VESIENTUTKIMUSLAITOKSEN JULKAISUJA
PUBLICATIONS OF THE WATER RESEARCH INSTITUTE **50**

Pertti Seuna: Influence of physiographic factors on maximum runoff
Tiivistelmä: Aluetekijöiden vaikutus pienten alueiden ylivalumiin 5

Pertti Seuna: Infiltration and its dependence on some physiographic factors
Tiivistelmä: Infiltraatio ja sen riippuvuus eräistä aluetekijöistä 29

VESIHALLITUS—NATIONAL BOARD OF WATERS, FINLAND
Helsinki 1983

Tekijä on vastuussa julkaisun sisällöstä, eikä siihen voida vedota vesihallituksen virallisena kannanottona.

The author is responsible for the contents of the publication. It may not be referred to as the official view or policy of the National Board of Waters.

ISBN 951-46-6723-9
ISSN 0355-0982

Helsinki 1983. Valtion painatuskeskus

CONTENTS

Influence of physiographic factors on maximum runoff

1.	Introduction	5
2.	Methods and data	5
3.	Spring maximum runoff	6
4.	Summer maximum runoff	14
5.	Runoff ratios	17
5.1	Spring	17
5.2	Summer	19
6.	Influence of independent variables	20
7.	Discussion	24
	Acknowledgements	25
	Lopputiivistelmä	25
	List of symbols	26
	References	27

Infiltration and its dependence on some physiographic factors

1.	Introduction	29
2.	Method	30
3.	Fitting of the infiltration equations	30
4.	Dependence of infiltration on some physiographic and meteorologic factors	34
4.1	Soil characteristics	34
4.2	Antecedent precipitation index	35
4.3	Influence of soil characteristics and moisture conditions on infiltration capacity	36
5.	Discussion	37
	Acknowledgements	38
	Lopputiivistelmä	38
	References	39

INFLUENCE OF PHYSIOGRAPHIC FACTORS ON MAXIMUM RUNOFF

Pertti Seuna

SEUNA, P. 1983. Influence of physiographic factors on maximum runoff. Publications of the Water Research Institute, National Board of Waters, Finland, No. 50.

Physiographic factors were used as the independent variables in a multivariate regression analysis to explain a long term average and a 20-year value of spring and summer maximum runoffs. A satisfactory degree of determination was reached in general, using two to four characteristics, defined from maps or readily available statistics. The altitude of the basin, the percentages of fine soils and impermeable surfaces, and the density of drainage network increased significantly both spring and summer maximum runoffs. The volume of growing stock remarkably decreased spring maximum runoff, while high percentages of cultivated land increased it. Drainage area explained significantly the instantaneous and exceptional maxima, those of summer especially.

Index words: maximum runoff, physiographic factors, multivariate regression analysis, extremity, peaked tendency.

1. INTRODUCTION

A network of small hydrological basins in Finland was completely renewed in 1958 to 1962 (Mustonen 1965b, 1965c). Measuring weirs were built with continuous water stage recording and various meteorological observations were begun. Physiographic factors were studied using maps and point line surveys. At the end of 1977 part of the basins had been in operation for 20 years. On the basis of the observation data from 1958 to 1977 frequency analyses were carried out for various runoff quantities using observation series ten years or more in length (Seuna 1982). Thirty seven basins of the total amount of 58 were available for this analysis (Fig. 1 and 2, Table 1).

In this study regression analyses of maximum runoff are presented based on the frequency analyses mentioned.

2. METHODS AND DATA

Using a multivariate regression analysis equations for spring and summer maximum runoffs were calculated. Only variables, which could be defined from maps or from readily available statistics were

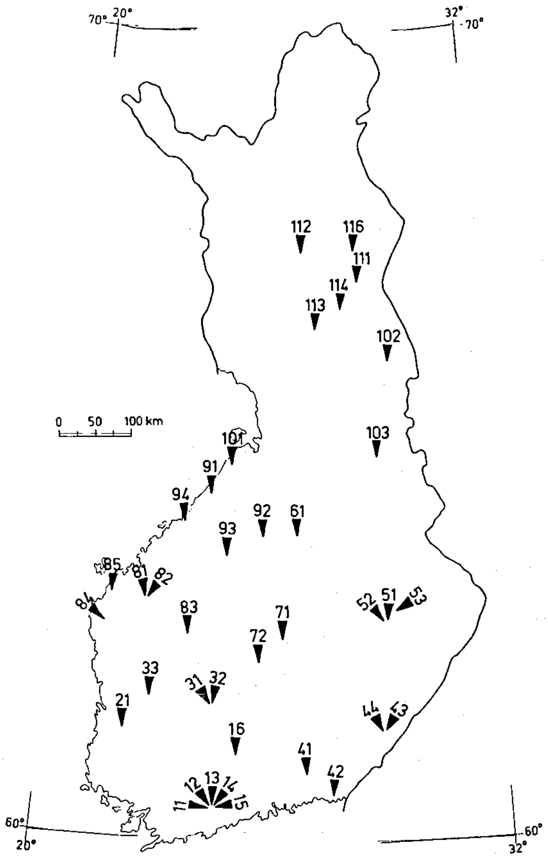

Fig. 1. A network of thirty seven small basins used in the regression analysis.

used. These were e.g. drainage area, percentage of cultivated land, altitude, volume of growing stock, etc. Some long-term averages of meteorological factors were also included and these can be regarded as basin factors as well. In the analysis 37 basins with observation series ten or more years were included (n = 37).

The dependent variables were as follows

MHq_w	=	mean value of the spring maximum runoff
MHq_s	=	mean value of the summer maximum runoff
$MHq_{w\ inst}$	=	mean value of the instantaneous spring maximum
$MHq_{s\ inst}$	=	mean value of the instantaneous summer maximum
$Hq_w 1/20$	=	spring maximum runoff with return period of 20 years
$Hq_s 1/20$	=	summer maximum runoff with return period of 20 years
$Hq_{w\ inst} 1/20$	=	instantaneous spring maximum with return period of 20 years
$Hq_{s\ inst} 1/20$	=	instantaneous summer maximum with return period of 20 years

In addition to this, the ratios of $MHq_{w\ inst}$ and MHq_w; Hq_w 1/20 and MHq_w; $Hq_{w\ inst}$ 1/20 and Hq_w 1/20; $Hq_{w\ inst}$ 1/20 and MHq_w; and the respective ratios for summer maximum were explained using the same independent variables.

The independent variables, with their means, standard deviations and variation ranges, used in the regression analysis, are presented in Table 2. The correlation matrices of the independent and dependent variables are shown in Tables 3 and 4, respectively.

A number of transformations of the independent variables were tested, such as A, ln A, $(\ln A)^{-1}$, $A^{1/2}$, $A^{1/3}$, A^{-1}, $A^{-1/2}$, $A^{-1/3}$, C, C^2, C_s, F, B, B_o, B_d, b_i, $b_i^{1/2}$, I_s, I_s^2, $C + I_s$, $(C + I_s)^2$, $C + B + I_s$, D_d, D_d^2, F_s, $F_s^{1/2}$, $F_s^{1/3}$, $F_s^{1/4}$, $F_s^{1/5}$, $F_s^{1/6}$, $F_s^{1/8}$, $F_s^{1/9}$, $F_s^{1/10}$, $F_s^{1/12}$, ln F_s, F_c, G_r, G_f, G_f^2, $G_f + I_s$, $(G_f + I_s)^2$, G_c, G_c^2, $G_c + I_s$, $(G_c + I_s)^2$, G_g, L_b, k_e, k_c, L_c, S_c, L_w, S_w, E_w, E_o, E_p, E_d, S_m, s_i, t_w, T_a, P_a, P_a^2, P_s, P_s^2, W_m, W_h, W_e, W_p.

In the transformations ln A and $(\ln A)^{-1}$, A was taken in hectares in order to avoid values of A smaller than one.

In Tables 5 and 6 the ten best independent variables to explain maximum runoffs and the ratios of runoff are presented. The best transformation of each variable has been taken. For the runoff ratios the root transformations of F_s were not tried.

3. SPRING MAXIMUM RUNOFF

Mean spring maximum runoff (MHq_w) could be best explained by tree stand ($F_s^{1/3}$, r = −0.68; F_c, r = −0.52), the altitude of the basin (E_w, E_o, E_p; r = 0.58, 0.61, 0.53, respectively), average snow cover (W_m, W_h, W_e, W_p; r = 0.52, 0.57, 0.54, 0.55, respectively), mean annual temperature (T_a, r =

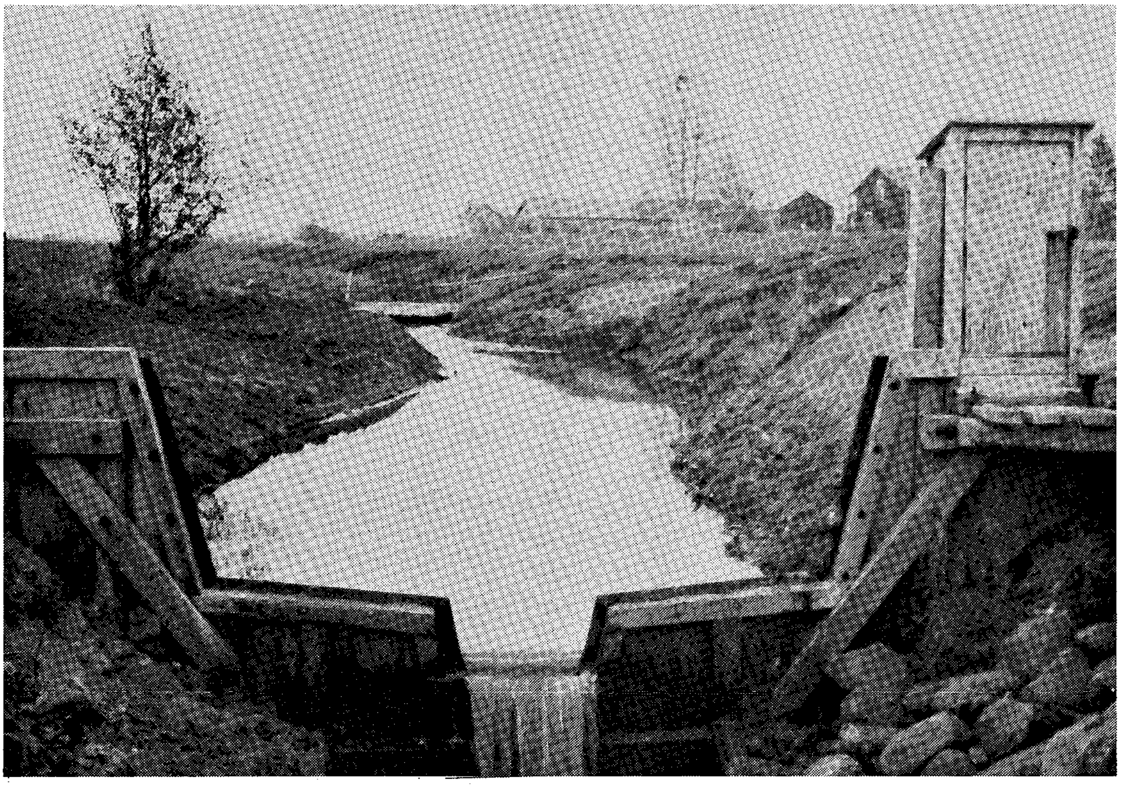

Fig. 2. The measuring weir of the Tuuraoja basin (No 91, Fig. 1).

−0.49) and the percentage of open bog (B_o,r = 0.45). Some of the best combinations are presented in equations (1) — (9).

$\overline{MHq_w} = 118.6\ \mathrm{l\ s^{-1}\ km^{-2}}$, $s_y = 37.8\ \mathrm{l\ s^{-1}\ km^{-2}}$

$$MHq_w = -31\ F_s^{1/3} + 228 \qquad (1)$$
R = 0.676
$s_e = 28$

$$MHq_w = -28\ F_s^{1/3} + 0.33\ E_o + 191 \qquad (2)$$
R = 0.866
$s_e = 19$

$$MHq_w = -0.52\ F_s + 0.017\ C^2 - 1.0\ C + 0.30\ E_o + 125 \qquad (3)$$
R = 0.870
$s_e = 20$

$$MHq_w = -0.50\ F_s + 0.018\ (C + I_s)^2 - 1.2\ (C + I_s) + 0.29\ E_o + 126 \qquad (4)$$
R = 0.875
$s_e = 19$

$$MHq_w = -0.71\ F_s + 0.019\ C^2 - 1.4\ C + 0.63\ W_m + 96 \qquad (5)$$
R = 0.871
$s_e = 20$

$$MHq_w = -0.57\ F_s + 0.015\ C^2 - 0.88\ C + 0.19\ E_o + 0.40\ W_m + 90 \qquad (6)$$
R = 0.887
$s_e = 19$

$$MHq_w = -0.91\ F_s + 0.33\ E_o + 21\ A^{-1/2} + 125 \qquad (7)$$
R = 0.885
$s_e = 18$

$$MHq_w = -0.93\ F_s + 0.34\ W_m + 0.23\ E_o + 20\ A^{-1/2} + 98 \qquad (8)$$
R = 0.896
$s_e = 18$

$$MHq_w = -29\ F_s^{1/3} + 0.23\ E_o + 0.37\ W_m + 160 \qquad (9)$$
R = 0.880
$s_e = 19$

Table 1. Data on basin characteristics at the end of the observation period 1958—1977.

Drainage basin	Area km²	Cultivated land %	Peat land %	Forest on firm land %	Tree stand m^3ha^{-1}	Mean slope %	Max altitude m a.s.l.
11. Hovi	0.12	100	0	0	0	2.8	56
12. Ali-Knuutila	0.24	48	0	42	55	10.0	90
13. Yli-Knuutila	0.07	0	0	100	162	16.0	92
14. Teeressuonoja	0.69	0	13	87	116	13.9	111
15. Kylmänoja	4.04	27	11	60	52	8.2	115
16. Koiranoja	6.21	26	11	58	73	7.0	177
21. Löytäneenoja	5.64	77	1	20	19	1.7	53
31. Paunulanpuro	1.50[1)]	2	18	77	82	6.8	147
32. Siukolanpuro	1.86[2)]	9	16	74	48	7.5	147
33. Katajaluoma	11.2	3	43	54	45	2.9	165
41. Niittyjoki	29.7	35	2	59	45	4.9	107
42. Ravijoki	56.9	17	25	56	50	6.4	63
43. Latosuonoja	5.34	19	15	66	74	8.2	131
44. Huhtisuonoja	5.03	0	44	56	39	5.0	132
51. Kesselinpuro	21.7	4	39	54	88	4.2	149
52. Kuokkalanoja	2.76	21	14	62	72	5.8	145
53. Mustapuro	11.2	15	34	51	60	3.2	123
61. Korpijoki	122	8	65	27	44	3.1	200
71. Ruunapuro	5.39	22	10	67	66	6.4	176
72. Heinäjoki	9.40	8	10	81	76	7.6	218
81. Haapajyrä	6.09	58	15	26	23	3.0	47
82. Kainastonluoma	79.2	27	20	51	53	3.8	63
83. Kaidesluoma	45.5	13	26	59	46	3.3	178
84. Norrskogsdiket	11.6	34	30	36	48	1.6	41
85. Sulvanjoki	26.8	23	11	65	67	3.6	46
91. Tuuraoja	23.5	16	47	40	27	2.0	55
92. Tujuoja	20.6	12	40	43	46	2.3	152
93. Pahkaoja	23.3	2	53	43	40	2.1	202
94. Kuikkisenoja	8.05	31	22	47	62	3.9	28
101. Huopakinoja	19.7	17	26	56	53	2.6	76
102. Vääräjoki	19.3	0	34	64	30	5.0	354
103. Myllypuro	9.86	2	27	70	59	7.4	259
111. Kuusivaaranpuro	27.6	2	26	71	30	5.2	324
112. Lismanoja	2.77	2	37	57	16	7.8	350
113. Korintteenoja	6.13	2	5	92	37	10.2	352
114. Vähä-Askanjoki	16.4	0	17	83	14	10.9	383
116. Myllyoja	28.5	1	12	87	40	7.4	411
Mean	18.27	18.5	22.1	57.9	52.9	5.8	159.9
Standard deviation	24.27	22.4	16.1	20.8	29.3	3.4	106.0

1) before 3/1968 A = 3.01 km², 2) before 3/1968 A = 3.37 km²

In these equations the independent variables are significant at the risk < 0.1 per cent, except for C in eq. (3) and (6), C + I_s in eq. (4), E_o in eqs. (8) and (9) (risk < 1 per cent), and E_o in eq. (6), and W_m in eq. (6) and (8) (risk < 5 per cent). The T-value of the variable W_m in eq. (9) is 1.92, which is little below the 5 per cent risk level. The equations (4), (7) and (9) are presented as nomographs in Figs. 3,4 and 5, respectively.

The best independent variables to explain the variance of the mean spring maximum runoff were tree stand, the altitude of the basin, the water equivalent of snow and the annual mean temperature. Of the factors indicating tree stand, the volume of growing stock was somewhat better than the coverage of tree stand (r = −0.63 and −0.52, respectively). An increase of 10 m³ ha^{-1} in the growing stock decreased spring maximum

Table 2. The mean values, standard deviations, and variation ranges of the independent variables (see the list of symbols).

Variable	Unit	Mean	Standard deviation	Minimum	Maximum
A	km^2	18.3	24.3	0.068	122.0
C	%	18.5	22.4	0.0	100.0
C_s	%	11.4	17.0	0.0	60.0
F	%	57.9	20.7	0.0	100.0
B	%	23.0	17.1	0.0	65.0
B_o	%	6.7	9.3	0.0	34.0
B_d	%	9.2	11.0	0.0	47.0
b_i	—	1.70	1.94	0.0	9.4
I_s	%	1.32	1.56	0.0	8.0
D_d	km^{-1}	1.54	0.95	0.70	5.0
F_s	m^3ha^{-1}	52.5	28.4	0.0	162.0
F_c	%	31.3	13.2	0.0	70.0
G_r	%	57.2	18.8	0.0	88.0
G_f	%	14.1	18.3	0.0	75.0
G_c	%	7.4	13.0	0.0	55.0
G_g	%	2.6	4.3	0.0	17.0
L_b	km	6.3	4.5	0.3	18.8
k_e	—	0.41	0.19	0.14	0.89
k_c	—	0.50	0.17	0.26	0.90
L_c	km	7.5	5.9	0.2	27.2
S_c	%	1.09	1.77	0.12	10.0
L_w	km	4.0	3.1	0.2	12.3
S_w	%	1.04	1.87	0.10	10.9
E_w	m	103	68	9	283
E_o	m	87	62	4	258
E_p	m	160	106	28	411
E_d	m	73	57	12	242
S_m	%	5.8	3.4	1.6	16.0
s_i	‰	11.2	17.0	0.8	93.8
t_w	h	1.22	0.96	0.06	4.4
T_a	°C	2.8	1.47	−0.7	4.5
P_a	mm	653	60	540	740
P_s	mm	191	19	141	226
W_m	mm	113	24	72	157
W_h	mm	113	33	58	185
W_e	mm	116	40	47	203
W_p	mm	124	38	61	203

runoff about 7 $l\ s^{-1}\ km^{-2}$. The nonlinear transformation ($F_s^{1/3}$, $r = -0.68$) entered some models instead of the linear form. The altitude of the outlet explained MHq_w better than the altitude of the centre of gravity or the highest point. It is rather interesting that the altitude proved to explain MHq_w slightly better than the more directly physical factor, the water equivalent of snow (Table 5). The rise of 10 meters in the altitude increased spring maximum runoff about 3—4 $l\ s^{-1}\ km^{-2}$. Respectively an increase of 10 mm in the water equivalent of snow increased MHq_w about 8 $l\ s^{-1}\ km^{-2}$. Drainage area did not prove to explain especially well MHq_w, although it was significant in some combinations. The transformation $A^{-1/2}$ turned out to be the best one of the tested area factors.

Instantaneous spring maximum runoff ($MHq_{w\ inst}$) was best explained by tree stand ($F_s^{1/6}$, $r = -0.78$; F_c, $r = -0.54$), fine fractions of soil (G_c^2, $r = 0.62$; G_f^2, $r = 0.60$), the percentage of cultivated land (C^2, $r = 0.60$), drainage density (D_d^2, $r = 0.58$) and drainage area ($A^{-1/3}$, $r = 0.41$). Some combinations for $MHq_{w\ inst}$ are presented in eqs. (10) — (17).

$MHq_{w\ inst} = 157.4\ l\ s^{-1}\ km^{-2}$, $s_y = 72.2\ l\ s^{-1}\ km^{-2}$

$$MHq_{w\ inst} = -161\ F_s^{1/6} + 457 \quad R = 0.775 \quad s_e = 46 \tag{10}$$

$$MHq_{w\ inst} = 108\ A^{-1/3} - 2.0\ F_s + 198 \quad R = 0.842 \quad s_e = 40 \tag{11}$$

$$MHq_{w\ inst} = 0.092\ G_f^2 - 2.6\ G_f + 0.55\ E_o + 98 \quad R = 0.862 \quad s_e = 38 \tag{12}$$

Table 3. Correlation matrix of the independent variables (see the list of symbols).

	A	C	C_s	F	B_o	I_s	B	B_d	b_t	D_d	F_s	F_c	G_r	G_t	G_c	G_g
A	1.00															
C	−0.14	1.00														
C_s	−0.08	0.64	1.00													
F	0.21	−0.74	−0.41	1.00												
B_o	0.02	−0.34	−0.23	−0.10	1.00											
I_s	−0.18	0.19	−0.03	0.10	−0.27	1.00										
B	0.44	−0.45	−0.35	−0.26	0.61	−0.45	1.00									
B_d	0.11	−0.31	−0.22	−0.12	0.29	−0.36	0.61	1.00								
b_t	0.16	−0.32	−0.22	−0.13	0.42	−0.40	0.63	0.88	1.00							
D_d	−0.38	0.55	0.18	−0.27	−0.24	0.28	−0.44	−0.14	−0.19	1.00						
F_s	−0.13	−0.37	−0.15	0.59	−0.37	0.23	−0.24	−0.06	−0.11	0.05	1.00					
F_c	−0.01	−0.51	−0.22	0.61	−0.29	0.15	−0.09	0.07	−0.01	−0.11	0.83	1.00				
G_r	−0.12	−0.57	−0.15	0.79	−0.06	−0.17	−0.23	−0.11	−0.05	−0.44	0.24	0.32	1.00			
G_t	−0.18	0.87	0.53	−0.50	−0.41	0.43	−0.59	−0.39	−0.44	0.66	−0.09	−0.22	−0.60	1.00		
G_c	−0.07	0.86	0.44	−0.59	−0.28	0.28	−0.45	−0.29	−0.33	0.57	−0.26	−0.34	−0.61	0.92	1.00	
G_g	0.07	−0.03	−0.18	0.06	0.03	0.42	−0.05	−0.18	−0.09	0.15	0.27	0.15	−0.22	0.16	0.02	1.00
L_b	0.84	−0.21	−0.13	−0.17	0.23	−0.24	0.52	0.16	0.23	−0.55	−0.29	−0.13	−0.00	−0.33	−0.16	0.12
k_c	−0.18	0.10	0.19	0.21	−0.44	0.11	−0.40	−0.16	−0.18	0.35	0.50	0.34	0.01	0.26	0.13	−0.09
k_s	−0.23	0.00	−0.09	0.23	−0.36	0.15	−0.28	−0.22	−0.18	0.31	0.55	0.30	−0.06	0.19	0.07	0.05
L_s	0.89	−0.21	−0.16	−0.17	0.11	−0.24	0.50	0.17	0.23	−0.53	−0.24	−0.07	−0.00	−0.33	−0.18	0.10
S_c	−0.29	−0.09	−0.14	0.44	−0.27	0.42	−0.43	−0.30	−0.33	0.34	0.62	0.43	−0.03	0.23	0.08	0.36
L_w	0.83	−0.24	−0.15	−0.17	0.21	−0.23	0.56	0.18	0.24	−0.53	−0.24	−0.10	−0.03	−0.36	−0.22	0.16
S_w	0.28	−0.08	−0.13	0.40	−0.24	0.44	−0.39	−0.27	−0.31	0.37	0.64	0.48	−0.09	0.25	0.09	0.39
E_w	−0.01	−0.57	−0.43	0.40	0.42	−0.23	0.26	−0.01	−0.02	−0.29	−0.20	−0.06	0.37	−0.56	−0.49	−0.25
E_o	−0.05	−0.53	−0.41	0.35	0.47	−0.26	0.28	0.02	0.01	−0.25	−0.21	−0.07	0.33	−0.53	−0.46	−0.26
E_p	0.02	−0.56	−0.42	0.50	0.33	−0.20	0.13	−0.09	−0.06	−0.35	−0.21	−0.09	0.51	−0.56	−0.47	−0.23
E_d	0.10	−0.47	−0.35	0.55	0.10	−0.08	−0.06	−0.18	−0.12	−0.38	−0.16	−0.08	0.60	−0.45	−0.38	−0.14
S_m	−0.32	−0.35	−0.32	0.74	−0.21	0.42	−0.49	−0.41	−0.40	0.12	0.58	0.44	0.42	−0.05	−0.18	0.25
s_t	−0.30	−0.09	−0.16	0.44	−0.25	0.42	−0.43	−0.33	−0.34	0.34	0.65	0.44	−0.01	0.21	0.08	0.33
t_w	0.63	−0.08	−0.06	−0.28	0.22	−0.20	0.47	0.13	0.22	−0.45	−0.23	−0.14	−0.11	−0.21	−0.09	0.33
T_a	−0.15	0.51	0.43	−0.33	−0.38	0.31	−0.29	−0.02	−0.09	0.48	0.38	0.18	−0.42	0.59	0.47	0.19
P_a	−0.16	−0.04	−0.16	0.19	−0.25	0.10	−0.21	0.08	−0.04	0.38	0.37	0.26	0.01	0.12	0.15	0.08
W_m	−0.02	−0.44	−0.54	0.41	0.18	−0.10	0.06	−0.08	−0.01	−0.12	−0.02	0.02	0.30	−0.37	−0.25	−0.04
P_s	−0.11	−0.33	−0.34	0.37	0.04	−0.11	−0.02	−0.04	−0.10	0.01	0.01	−0.01	0.26	−0.25	−0.16	−0.31
W_h	−0.03	−0.56	−0.57	0.46	0.35	−0.26	0.19	−0.02	0.05	−0.27	−0.17	−0.06	0.43	−0.54	−0.40	−0.09
W_e	0.01	−0.61	−0.57	0.48	0.38	−0.29	0.23	0.02	0.09	−0.33	−0.17	−.04	0.46	−0.61	−0.48	−0.12
W_p	−0.02	0.57	−0.57	0.46	0.33	−0.27	0.19	0.01	0.05	−0.28	−0.16	−0.03	0.42	−0.54	−0.40	−0.11

	L_b	k_c	k_s	L_s	S_c	L_w	S_w	E_w	E_o	E_p	E_d	S_m	s_t	t_w	T_a	P_a	W_m	P_s	W_h	W_e	W_p
L_b	1.00																				
k_c	−0.57	1.00																			
k_s	−0.54	0.76	1.00																		
L_s	0.97	−0.49	−0.45	1.00																	
S_c	−0.45	0.40	0.57	−0.42	1.00																
L_w	0.98	−0.53	−0.46	0.97	−0.43	1.00															
S_w	−0.45	0.40	0.56	−0.41	0.98	−0.42	1.00														
E_w	0.10	−0.22	−0.12	0.08	−0.04	0.11	−0.06	1.00													
E_o	−0.06	−0.20	−0.12	0.03	−0.10	0.06	−0.11	0.99	1.00												
E_p	0.16	−0.25	−0.13	0.14	−0.01	0.14	−0.06	0.94	0.90	1.00											
E_d	0.23	−0.25	−0.11	0.23	0.08	0.19	−0.00	0.67	0.58	0.88	1.00										
S_m	−0.44	0.37	0.49	−0.41	0.74	−0.44	0.72	0.21	0.17	0.31	0.40	1.00									
s_t	−0.47	0.46	0.63	−0.43	0.97	−0.45	0.96	−0.03	−0.08	0.00	0.09	0.80	1.00								
t_w	0.86	−0.57	−0.48	0.82	−0.47	0.89	−0.45	−0.17	−0.18	−0.13	−0.06	−0.51	−0.49	1.00							
T_a	−0.35	0.39	0.21	−0.33	0.20	−0.34	0.25	−0.79	−0.76	−0.87	−0.79	−0.03	0.21	−0.14	1.00						
P_a	−0.32	0.34	0.29	−0.27	0.32	−0.31	0.31	0.05	0.08	0.01	−0.06	0.44	0.36	−0.36	0.31	1.00					
W_m	0.01	0.00	0.14	0.04	0.12	0.01	0.08	0.74	0.73	0.75	0.61	0.44	0.18	−0.20	−0.61	0.44	1.00				
P_s	−0.17	0.08	0.14	−0.13	0.20	−0.16	0.16	0.75	0.73	0.70	0.51	0.40	0.22	−0.42	−0.42	0.51	0.72	1.00			
W_h	0.09	−0.18	−0.01	0.08	−0.02	0.07	−0.06	0.82	0.81	0.87	0.74	0.34	0.01	−0.12	−0.79	0.23	0.91	0.65	1,00		
W_e	0.14	−0.21	−0.04	0.12	−0.04	0.12	−0.09	0.84	0.82	0.89	0.77	0.31	−0.02	−0.09	−0.84	0.15	0.88	0.63	0.99	1.00	
W_p	0.10	−0.18	−0.03	0.09	−0.03	0.08	−0.08	0.82	0.80	0.86	0.73	0.32	−0.01	−0.12	−0.78	0.24	0.90	0.65	1.00	0.99	1.00

Table 4. Correlation matrix of the dependent variables.

		y 1	y 2	y 3	y 4	y 5	y 6	y 7	y 8	y5/y1	y6/y2	y7/y3	y8/y4	y3/y1	y4/y2	y7/y1	y8/y2
MHq_w	= y 1	1.00															
MHq_s	= y 2	0.64	1.00														
$MHq_{w\ inst}$	= y 3	0.87	0.70	1.00													
$MHq_{s\ inst}$	= y 4	0.39	0.75	0.71	1.00												
Hq_w 1/20	= y 5	0.91	0.58	0.86	0.48	1.00											
Hq_s 1/20	= y 6	0.47	0.80	0.72	0.88	0.53	1.00										
$Hq_{w\ inst}$ 1/20	= y 7	0.78	0.64	0.96	0.71	0.87	0.74	1.00									
$Hq_{s\ inst}$ 1/20	= y 8	0.33	0.63	0.69	0.95	0.47	0.87	0.75	1.00								
Hq_w 1/20/MHq_w	= y 5/y 1	−0.28	−0.22	−0.12	0.11	0.12	0.04	0.11	0.25	1.00							
Hq_s 1/20/MHq_s	= y 6/y 2	−0.12	0.06	0.18	0.41	0.04	0.61	0.28	0.55	0.35	1.00						
$Hq_{w\ inst}$1/20/$MHq_{w\ inst}$	= y 7/y 3	−0.25	−0.22	−0.12	−0.03	0.10	0.02	0.16	0.15	0.88	0.30	1.00					
$Hq_{s\ inst}$ 1/20/$MHq_{s\ inst}$	= y 8/y 4	−0.03	0.14	0.22	0.37	0.17	0.50	0.37	0.59	0.47	0.69	0.48	1.00				
$MHq_{w\ inst}$/MHq_w	= y 3/y 1	0.29	0.50	0.69	0.85	0.37	0.75	0.70	0.86	0.12	0.52	0.03	0.48	1.00			
$MHq_{s\ inst}$/MHq_s	= y 4/y 2	0.07	0.41	0.44	0.87	0.18	0.67	0.46	0.88	0.24	0.54	0.04	0.45	0.83	1.00		
$Hq_{w\ inst}$ 1/20/MHq_w	= y 7/y 1	0.10	0.28	0.49	0.66	0.38	0.63	0.67	0.78	0.61	0.59	0.62	0.68	0.79	0.67	1.00	
$Hq_{s\ inst}$ 1/20/MHq_s	= y 8/y 2	0.06	0.36	0.42	0.80	0.23	0.70	0.51	0.91	0.37	0.67	0.24	0.72	0.78	0.93	0.76	1.00

Table 5. The ten best independent variables to explain maximum runoffs, and the correlation coefficients vs. runoff.

Dependent variable	Independent variable and correlation coefficient									
MHq_w	$F_s^{1/2}$	E_o	E_w	W_h	W_p	W_e	E_p	F_c	W_m	T_a
	−0.68	0.61	0.58	0.57	0.55	0.54	0.53	−0.52	0.52	−0.49
MHq_s	P_s^2	W_m	G_c^2	$F_s^{1/8}$	G_f^2	D_d^2	t_w	W_p	C^2	W_h
	0.50	0.49	0.47	−0.47	0.45	0.42	−0.41	0.38	0.38	0.38
$MHq_{w\ inst}$	$F_s^{1/6}$	G_c^2	C^2	G_f^2	D_d^2	F_c	$A^{-1/3}$	F	G_r	W_m
	−0.78	0.62	0.60	0.60	0.58	−0.54	0.41	−0.40	−0.40	0.34
$MHq_{s\ inst}$	$A^{-1/3}$	D_d^2	G_f^2	I_s^2	G_c^2	C^2	$F_s^{1/12}$	t_w	s_i	S_w
	0.76	0.70	0.70	0.67	0.62	0.55	−0.54	−0.49	0.48	0.48
Hq_w 1/20	$F_s^{1/3}$	F_c	B_o	F	G_r	C^2	G_c^2	E_o	G_f^2	D_d^2
	−0.68	−0.53	0.44	−0.43	−0.41	0.41	0.40	0.40	0.39	0.37
Hq_s 1/20	G_f^2	D_d^2	G_c^2	C^2	$F_s^{1/12}$	$A^{-1/3}$	t_w	I_s^2	B	P_a
	0.75	0.72	0.71	0.70	−0.61	0.61	−0.45	0.45	0.45	0.43
$Hq_{w\ inst}$ 1/20	$F_s^{1/8}$	G_c^2	G_f^2	C^2	D_d^2	F_c	G_r	F	$A^{-1/3}$	t_w
	−0.84	0.73	0.72	0.71	0.68	−0.55	−0.55	−0.53	0.46	−0.27
$Hq_{s\ inst}$ 1/20	$A^{-1/3}$	D_d^2	G_f^2	G_c^2	C^2	$F_s^{1/12}$	I_s^2	S_w	G_r	s_i
	0.84	0.80	0.78	0.70	0.66	−0.63	0.57	0.53	−0.52	0.50

Table 6. The ten best independent variables to explain the ratios of maximum runoff, and the correlation coefficients vs. runoff.

Dependent variable	Independent variable and correlation coefficient									
Hq_w 1/20/MHq_w	W_p	E_p	W_h	W_e	W_m	E_d	E_w	E_o	S_c	P_s^2
	−0.58	−0.57	−0.57	−0.56	−0.54	−0.52	−0.50	−0.49	−0.48	−0.46
Hq_s 1/20/MHq_s	T_a	G_f	D_d	W_e	$A^{-1/3}$	C^2	W_p	W_h	E_p	E_d
	0.67	0.64	0.62	−0.61	0.59	0.58	−0.57	−0.56	−0.54	−0.52
$Hq_{w\ inst}$ 1/20/$MHq_{w\ inst}$	W_p	W_h	E_p	W_m	W_e	E_d	E_w	E_o	G_r	P_s^2
	−0.61	−0.61	−0.60	−0.60	−0.59	−0.57	−0.53	−0.51	−0.49	−0.46
$Hq_{s\ inst}$ 1/20/$MHq_{s\ inst}$	D_d	ln A	T_a	G_f	C^2	E_d	L_w	L_c	L_b	E_p
	0.60	−0.56	0.56	0.54	0.50	0.46	−0.44	−0.44	−0.44	−0.44
$MHq_{w\ inst}$/MHq_w	ln A	G_f^2	D_d	G_c^2	C^2	L_w	L_b	L_c	I_s^2	t_w
	−0.74	0.73	0.70	0.65	0.64	−0.59	0.58	−0.58	0.56	−0.55
$MHq_{s\ inst}$/MHq_s	$A^{-1/3}$	S_w	s_i	S_c	I_s^2	D_d	G_f	L_b	$b_i^{1/2}$	L_w
	0.93	0.77	0.75	0.74	0.68	0.67	0.57	−0.57	−0.55	−0.54
$Hq_{w\ inst}$ 1/20/MHq_w	G_f^2	G_c^2	D_d^2	C^2	$A^{-1/3}$	G_r	T_a	W_e	E_p	F
	0.80	0.72	0.72	0.70	0.66	−0.66	0.56	−0.53	−0.52	−0.52
$Hq_{s\ inst}$ 1/20/MHq_s	$A^{-1/3}$	S_w	D_d	S_c	s_i	G_f^2	L_b	I_s^2	L_c	L_w
	0.94	0.76	0.74	0.72	0.71	0.64	−0.56	0.54	−0.54	−0.54

$$MHq_{w\ inst} = 106\ A^{-1/3} - 2.0\ F_s + 0.93\ W_m + 93$$
$$R = 0.896 \tag{13}$$
$$s_e = 33$$

$$MHq_{w\ inst} = 113\ A^{-1/3} - 1.9\ F_s + 0.34\ E_o + 158$$
$$R = 0.890 \tag{14}$$
$$s_e = 34$$

$$MHq_{w\ inst} = 83\ A^{-1/3} - 1.6\ F_s + 0.013\ (C + I_s)^2 - 0.63\ (C + I_s) + 0.99\ W_m + 82$$
$$R = 0.903 \tag{15}$$
$$s_e = 34$$

$$MHq_{w\ inst} = 96\ A^{-1/3} - 2.2\ F_s + 0.94\ W_m + 71\ k_e + 78$$
$$R = 0.908 \tag{16}$$
$$s_e = 32$$

$$MHq_{w\ inst} = 73\ A^{-1/3} - 1.3\ F_s + 0.039\ G_f^2 - 1.2\ G_f + 0.42\ E_o + 139$$
$$R = 0.906 \tag{17}$$
$$s_e = 33$$

In these equations the variables are significant at the risk < 0.1 per cent, except for W_m in eq. (15) (risk < 1 per cent) and k_e in eq. (16), F_s and E_o in eq. (17) (risk < 5 per cent). The variable $C + I_s$ in eq. (15) is not significant (T-value = 1.18), and the same holds with cultivated land in general in the equations for $MHq_{w\ inst}$. For practical reasons it was included in the equation (15), however. The variable G_f is not quite significant in eq. (17), although the T-value = 1.95 is near to the 5 per cent risk level. The equations (13) and (14) are presented in Figs. 6 and 7, respectively.

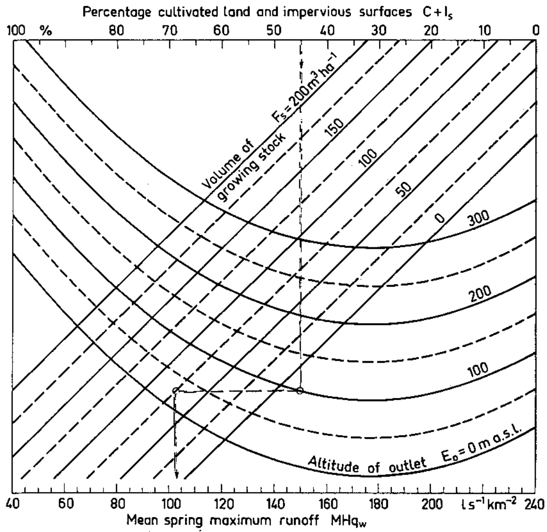

Fig. 3. A nomograph for the mean value of the spring maximum runoff $MHq_w = -0.50F_s + 0.018\,(C + I_s)^2 - 1.2\,(C + I_s) + 0.29\,E_o + 126.$

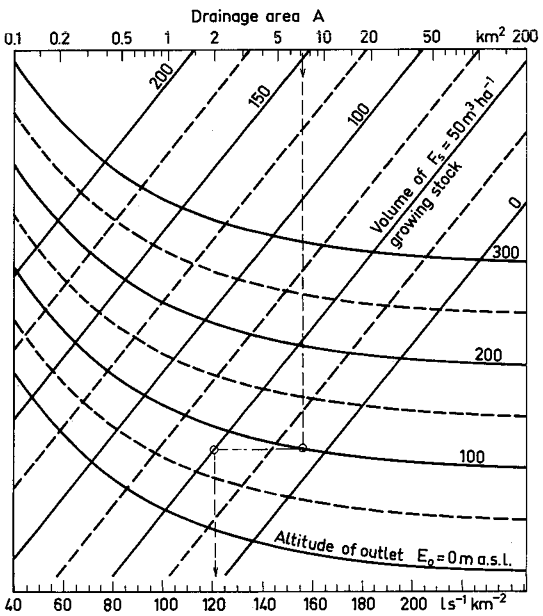

Fig. 4. A nomograph for the mean value of spring maximum runoff $MHq_w = -0.91\ F_s + 0.33\ E_o + 21\ A^{-1/2} + 125.$

As stated above, the instantaneous spring maximum runoff ($MHq_{w\ inst}$) was best explained by indices representing fine fractions of soil ($G_c^{\,2}$ $G_f^{\,2}$, r = 0.62, 0.60, respectively). The squared forms showed clearly better explaining ability in compa-

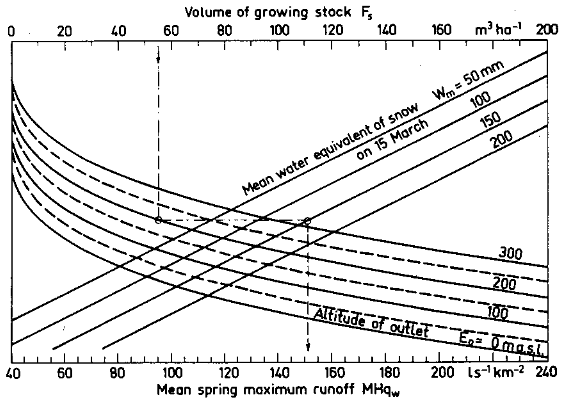

Fig. 5. A nomograph for the mean value of spring maximum runoff $MHq_w = -29\ F_s^{1/3} + 0.23\ E_o + 0.37\ W_m + 160.$

rison with the linear forms. In statistically significant correlation with $MHq_{w\ inst}$ were also tree stand (F_c and F_s, r = −0.54 and −0.53), the density of main channels (D_d, r = 0.49), drainage area ($A^{-1/3}$, r = 0.41), percentage of forest (F, r = −0.40), percentage of coarse soils (G_r,r = −0.40) and average water equivalent of snow on 15 March (W_m, r = 0.34). The transformation $F_s^{1/6}$ explained well $MHq_{w\ inst}$ (r = −0.78), but did not improve the models with two or more variables. The equation (16) explained 82 per cent of the variance of $MHq_{w\ inst}$, but still the standard error of estimate was 32 l s^{-1} km^{-2} or 20 per cent of $MHq_{w\ inst}$ and 44 per cent of the original standard deviation.

An increase of 1 m^3 ha^{-1} in the growing stock caused a decrease of 2 l s^{-1} km^{-2} in the instantaneous spring maximum runoff. A ten millimeters increase in the water equivalent of snow increased $MHq_{w\ inst}$ by 9—10 l s^{-1} km^{-2}. The percentage of impermeable surfaces had a very strong influence, being the best as a quadratic transformation. It decreased $MHq_{w\ inst}$ till about the percentage of six, but increased runoff remarkably in higher percentages. However, the range of impermeable surfaces was so narrow — only from 0 to 8 per cent — in the data base that it is not justified to assume as strong influence in higher percentages, say over ten.

For the spring maximum runoff with return period of 20 years (Hq_w 1/20) the best independent variables were tree stand (F_s and F_c, r = −0.60 and −0.53), the percentages of open bog (B_o, r = 0.44), forest (F, r = −0.43), coarse soils (G_r, r = −0.41), cultivated land (C^2, r = 0.41), clay soils (G_c^2, r = 0.40), the altitude (E_o, r = 0.40) and fine soils (G_f^2, r = 0.39). Of the F_s-transformations $F_s^{1/3}$

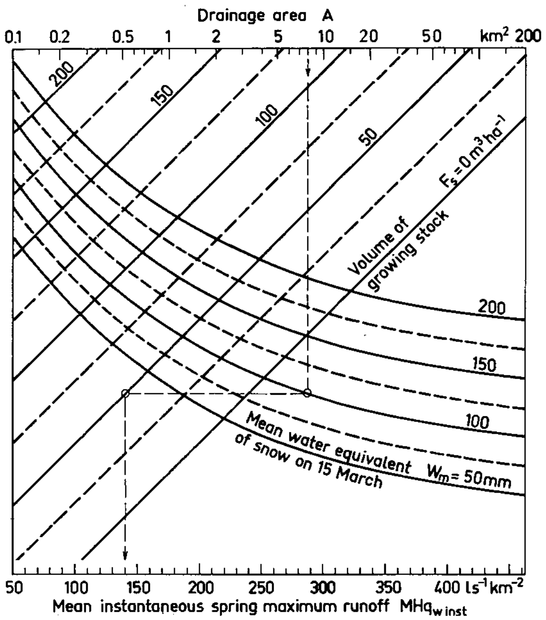

Fig. 6. A nomograph for the mean value of the instantaneous spring maximum runoff $MHq_{w\ inst} = 106\ A^{-1/3} - 2.0\ F_s + 0.93\ W_m + 93$.

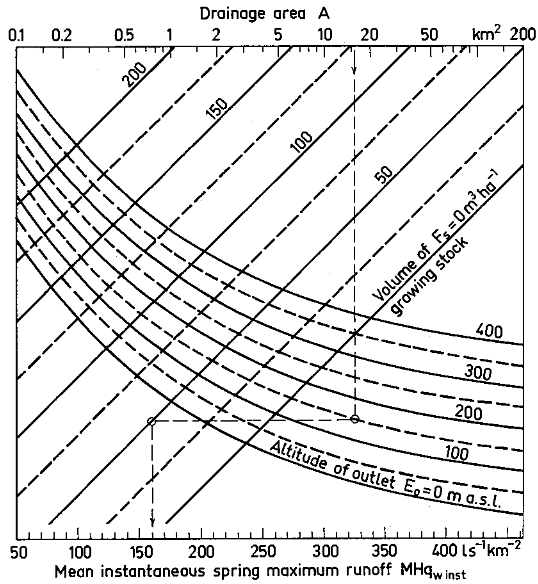

Fig. 7. A nomograph for the mean value of the instantaneous spring maximum runoff $MHq_{w\ inst} = 113\ A^{-1/3} + 0.34\ E_o - 1.9\ F_s + 158$.

correlated with Hq_w 1/20 slightly better ($r = -0.68$), than the linear form.

Some combinations for Hq_w 1/20 are presented in eqs. (18) — (22).

$Hq_w\ 1/20 = 223\ l\ s^{-1}\ km^{-2}$, $s_y = 70\ l\ s^{-1}\ km^{-2}$

$$Hq_w\ 1/20 = -57\ F_s^{1/3} + 428 \quad R = 0.678 \quad s_e = 52 \tag{18}$$

$$Hq_w\ 1/20 = -1.9\ F_s + 44\ A^{-1/2} + 301 \quad R = 0.745 \quad s_e = 48 \tag{19}$$

$$Hq_w\ 1/20 = -1.8\ F_s + 48\ A^{-1/2} + 0.39\ E_o + 257 \quad R = 0.817 \quad s_e = 42 \tag{20}$$

$$Hq_w\ 1/20 = -1.2\ F_s + 43\ A^{-1/2} + 0.57\ E_o - 1.16\ F + 278 \quad R = 0.845 \quad s_e = 40 \tag{21}$$

$$Hq_w\ 1/20 = -1.8\ F_s + 42\ A^{-1/2} + 0.28\ E_o + 0.014\ (C + I_s)^2 - 1.27\ (C + I_s) + 280 \quad R = 0.824 \quad s_e = 43 \tag{22}$$

In these equations the independent variables are significant at the risk < 0.1 per cent, except for E_o in eq. (20), F_s in eq. (21), which are significant at the < 1 per cent risk and F in eq. (21) and $A^{-1/2}$ in eq. (22) (risk < 5 per cent). E_o and $C + I_s$ in eq. (22) are not significant (T-values = 1.58 and 1.01, respectively). For practical reasons, however, the equation was taken. The equation (20) is presented as a nomograph in Fig. 8.

The influences of the growing stock, the altitude and the percentages of impermeable surfaces approximately equalled to their effects on $MHq_{w\ inst}$. The increase of the drainage area (A) from one to ten square kilometers caused a decrease of 30 $l\ s^{-1}\ km^{-2}$ and to 100 km² a decrease of 40 $l\ s^{-1}\ km^{-2}$ in Hq_w 1/20. The equation (21) explained 72 per cent of the variance of Hq_w 1/20.

The instantaneous spring maximum runoff with return period of 20 years ($Hq_{w\ inst}$ 1/20) was best explained by fine fractions of soil (G_c^2, G_f^2, C^2, r = 0.73, 0.72, 0.71, respectively) (Table 5). The density of main channels (D_d^2 $r = 0.68$), tree stand (F_c, $r = -0.55$, F_s, $r = -0.51$ and $F_s^{1/6}$, $r = -0.84$), the percentage of coarse soils (G_r, $r = -0.55$), forest percentage (F, $r = -0.53$) and drainage area ($A^{-1/3}$, $r = 0.46$) were also in statistically significant correlation with $Hq_{w\ inst}$ 1/20. Some combinations for $Hq_{w\ inst}$ 1/20 are presented in eqs. (23) – (28).

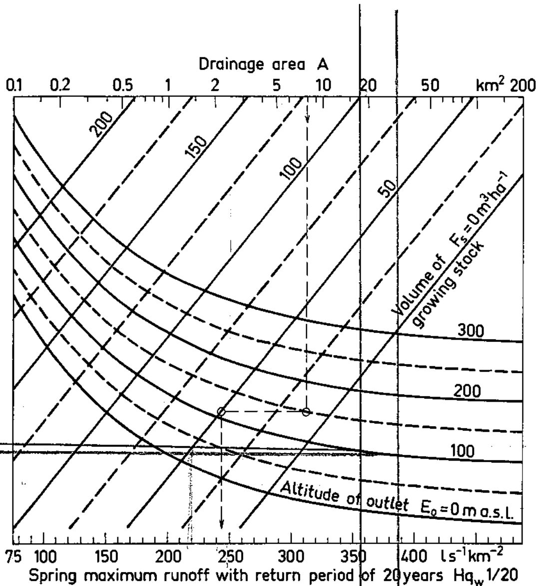

Fig. 8. A nomograph for the spring maximum runoff with return period of 20 years $Hq_w 1/20 = 48\ A^{-1/2} + 0.39\ E_o - 1.8\ F_s + 257$.

$Hq_{w\,inst}\ 1/20 = 293\ l\ s^{-1}\ km^{-2}$, $s_y = 149\ l\ s^{-1}\ km^{-2}$

$$Hq_{w\,inst}\ 1/20 = -358\ F_s^{1/6} + 966 \quad (23)$$
$R = 0.839$
$s_e = 83$

$$Hq_{w\,inst}\ 1/20 = -133\ F_s^{1/3} + 129\ A^{-1/3} + 699 \quad (24)$$
$R = 0.877$
$s_e = 74$

$$Hq_{w\,inst}\ 1/20 = 158\ A^{-1/3} - 2.8\ F_s + 0.112\ G_f^2 - 4.8\ G_f + 357 \quad (25)$$
$R = 0.895$
$s_e = 70$

$$Hq_{w\,inst}\ 1/20 = 179\ A^{-1/3} - 3.4\ F_s + 0.047\ C^2 - 3.0\ C + 386 \quad (26)$$
$R = 0.888$
$s_e = 73$

$$Hq_{w\,inst}\ 1/20 = 173\ A^{-1/3} - 3.3\ F_s + 0.054\ (C + I_s)^2 - 3.6\ (C + I_s) + 389 \quad (27)$$
$R = 0.890$
$s_e = 72$

$$Hq_{w\,inst}\ 1/20 = 113\ A^{-1/3} - 1.7\ F_s + 0.14\ G_f^2 - 4.7\ G_f + 3.8\ B_o + 288 \quad (28)$$
$R = 0.913$
$s_e = 65$

In these equations (23) — (28) the independent variables are significant at the risk < 0.1 per cent, except for A in eq. (25), G_f in eq. (28) (risk < 1 per cent) and G_f in eq. (25), C in eq. (26), $C + I_s$ in eq. (27) and A, F_s, B_o in eq. (28) (risk < 5 per cent). The equation (28) explained 83 per cent of the variance of $Hq_{w\,inst}\ 1/20$. A number of equations with the degree of determination around 90 per cent were rejected because of the quadratic transformation of the impervious surfaces, which was based on a very narrow range of data. The equation (27) is presented as a nomograph in Fig. 9.

In the equations (23) — (28) tree stand, fine soils and drainage area affected most. An increase of 1 $m^3\ ha^{-1}$ in growing stock caused a decrease of about 3 $l\ s^{-1}\ km^{-2}$ in $Hq_{w\,inst}\ 1/20$.

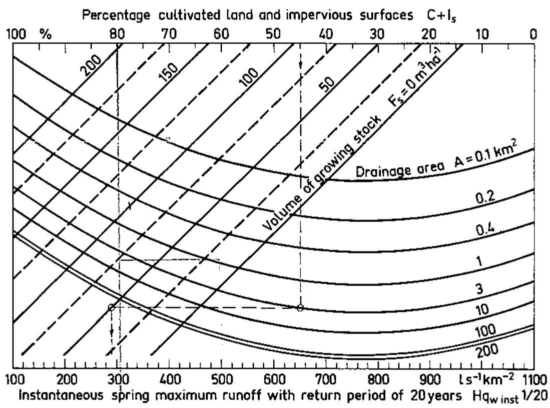

Fig. 9. A nomograph for the instantaneous spring maximum runoff with return period of 20 years $Hq_{w\,inst} 1/20 = 173\ A^{-1/3} + 0.054\ (C + I_s)^2 - 3.6\ (C + I_s) - 3.3\ F_s + 389$.

4. SUMMER MAXIMUM RUNOFF

The basin mean of daily summer maximum runoff (MHq_s) was best explained by the percentage of fine soils (G_f^2, G_c^2, r = 0.45, 0.47, resp.), summer precipitation (P_s, r = 0.50), tree stand ($F_s^{1/8}$, r = −0.47) and drainage density (D_d). The abundance of snow also indicated increased summer maximum runoff. In general MHq_s could not be explained satisfactorily with the variables used, as can be stated from eqs. (29) — (35).

$\overline{MHq_s} = 43.5\ l\ s^{-1}\ km^{-2}$, $s_y = 14.7\ l\ s^{-1}\ km^{-2}$

$$MHq_s = 0.38\ P_s - 29 \quad R = 0.500 \quad s_e = 12.9 \tag{29}$$

$$MHq_s = 0.80\ G_c + 0.16\ E_o + 24 \quad R = 0.712 \quad s_e = 10.6 \tag{30}$$

$$MHq_s = 0.012\ (I_s + G_c)^2 + 0.27\ (I_s + G_c) + 0.15\ E_o + 25 \quad R = 0.733 \quad s_e = 10.5 \tag{31}$$

$$MHq_s = 0.016\ (I_s + G_c)^2 + 0.13\ E_o + 0.055\ P_a - 8 \quad R = 0.761 \quad s_e = 10.0 \tag{32}$$

$$MHq_s = 0.72\ G_c + 0.16\ E_o + 0.36\ I_s + 22 \quad R = 0.755 \quad s_e = 10.1 \tag{33}$$

$$MHq_s = 0.70\ G_c + 0.15\ E_o + 1.25\ I_s^2 - 6.9\ I_s + 29 \quad R = 0.818 \quad s_e = 9.0 \tag{34}$$

$$MHq_s = 0.57\ G_c + 0.15\ E_o + 1.42\ I_s^2 - 9.0\ I_s - 0.26\ B + 38 \quad R = 0.852 \quad s_e = 8.3 \tag{35}$$

In these equations the independent variables are significant at the risk < 0.1 per cent, except for P_s in eq. (29) (risk < 1 per cent), I_s in eq. (33) and B in eg. (35), (risk < 5 per cent). In eq. (31) $I_s + G_c$ is not significant (T-value = 1.30), but the equation can be considered logical and practical. The same applies to P_a in eq. (32) (T-value = 1.94). The equation (32) is presented as a nomograph in Fig. 10.

The variable I_s in as a quadratic transformation, especially, was rather decisive to explain the variance of MHq_s. It was included in eqs. (33) — (35). The narrow data base, as mentioned before, makes the regression coefficients of I_s^2 unstable and high. For these reasons I_s-values greater than 8 per cent should not be used, which is the highest percentage of I_s in the data.

For the mean instantaneous summer maximum $MHq_{s\ inst}$ the best independent variables were drainage area ($A^{-1/3}$, r = 0.76), percentage of fine soils (G_f^2, r = 0.70; G_c^2, r = 0.62), drainage density (D_d, r = 0.68), the percentage of impervious surfaces (I_s^2, r = 0.67) and percentage cultivated

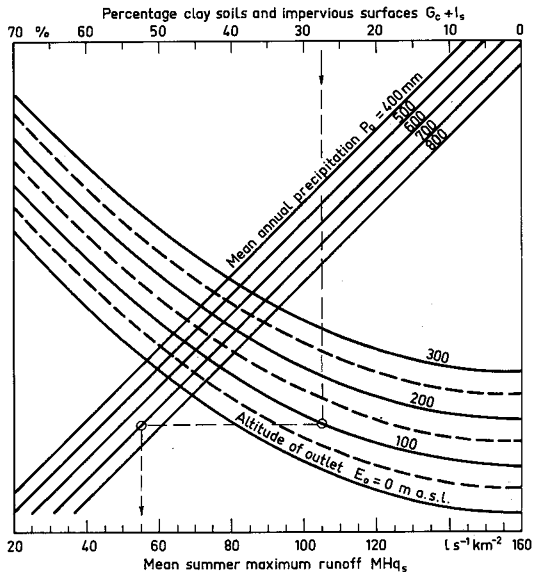

Fig. 10. A nomograph for the mean value of the summer maximum runoff $MHq_s = 0.016\ (G_c + I_s)^2 + 0.13\ E_o + 0.055\ P_a - 8$.

land (C^2, r = 0.55). Some combinations for $MHq_{s\ inst}$ are presented in eqs. (36) — (42).

$\overline{MHq_{s\ inst}} = 70.5\ l\ s^{-1}\ km^{-2}$, $s_y = 55.3\ l\ s^{-1}\ km^{-2}$

$$MHq_{s\ inst} = 88\ A^{-1/3} + 17 \quad R = 0.759 \quad s_e = 37 \tag{36}$$

$$MHq_{s\ inst} = 58\ A^{-1/3} + 0.021\ (I_s + G_f)^2 + 23 \quad R = 0.835 \quad s_e = 31 \tag{37}$$

$$MHq_{s\ inst} = 58\ A^{-1/3} + 0.045\ (I_s + G_f)^2 - 1.6\ (I_s + G_f) + 33 \quad R = 0.858 \quad s_e = 30 \tag{38}$$

$$MHq_{s\ inst} = 63\ A^{-1/3} + 0.036\ G_f^2 - 1.03\ G_f + 28 \quad R = 0.833 \quad s_e = 32 \tag{39}$$

$$MHq_{s\ inst} = 47\ A^{-1/3} + 0.052\ G_f^2 - 2.12\ G_f + 11.3\ I_s + 29 \quad R = 0.869 \quad s_e = 29 \tag{40}$$

$$MHq_{s\ inst} = 52\ A^{-1/3} + 0.017\ C^2 - 0.73\ C + 10.6\ I_s + 24 \quad R = 0.825 \quad s_e = 33 \tag{41}$$

$MHq_{s\,inst} = 40\ A^{-1/3} + 0.075\ G_c^2 - 1.77\ G_c + 5.2\ I_s^2 - 19\ I_s + 47$
$R = 0.952$ (42)
$s_e = 18$

In these equations the independent variables are significant at the risk < 0.1 per cent, except for A and I_s in eq. (40), and A in eq. (41), which are significant at the risk < 1 per cent, and G_f in eq. (39), I_s in eq. (41), which are significant at the risk < 5 per cent. The variable C in eq. (41) is not significant at the risk < 5 per cent (T-value = 1.64), however, for practical reasons a model containing field percentage was included. The equations, which include I_s in squared form, such as eq. (42), explain $MHq_{s\,inst}$ markedly well. They are, however, to be applied with caution and not for I_s greater than ten per cent. The equation (37) is presented as a nomograph in Fig. 11.

The summer maximum runoff with return period of 20 years (Hq_s 1/20) was best explained by the percentage of fine soils (G_f^2, r = 0.75; G_c^2, r = 0.71), drainage density (D_d, r = 0.71), field percentage (C^2, r = 0.70), drainage area ($A^{-1/3}$, r = 0.61) and tree stand ($F_s^{1/12}$, r = −0.61). Some combinations for Hq_s 1/20 are shown in eqs. (43) — (49).

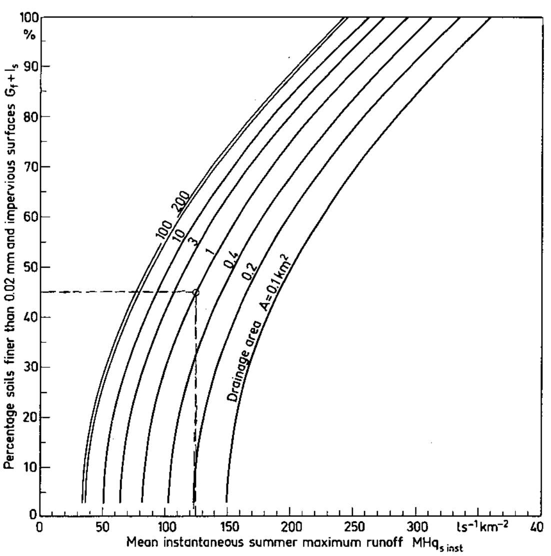

Fig. 11. A nomograph for the mean value of the instantaneous summer maximum runoff $MHq_{s\,inst} = 58\ A^{-1/3} + 0.021\ (G_f + I_s)^2 + 23$

$\overline{Hq_s\ 1/20} = 119.1\ l\ s^{-1}\ km^{-2}$, $s_y = 53.2\ l\ s^{-1}\ km^{-2}$

$Hq_s\ 1/20 = 0.037\ G_f^2 + 100$
$R = 0.753$ (43)
$s_e = 35$

$Hq_s\ 1/20 = 0.035\ G_f^2 + 0.31\ P_a - 101$
$R = 0.828$ (44)
$s_e = 31$

$Hq_s\ 1/20 = 0.037\ (G_f + I_s)^2 + 0.97\ P_s - 88$
$R = 0.843$ (45)
$s_e = 29$

$Hq_s\ 1/20 = 0.052\ G_f^2 - 1.13\ G_f + 0.31\ P_a - 94$
$R = 0.842$ (46)
$s_e = 30$

$Hq_s\ 1/20 = 0.058\ (G_f + I_s)^2 - 1.6\ (G_f + I_s) + 0.29\ P_a - 81$
$R = 0.861$ (47)
$s_e = 28$

$Hq_s\ 1/20 = 0.030\ C^2 - 1.09\ C + 0.31\ P_a + 9.2\ I_s - 100$
$R = 0.849$ (48)
$s_e = 30$

$Hq_s\ 1/20 = 0.026\ (C + I_s)^2 - 0.69\ (C + I_s) + 0.34\ P_a - 115$
$R = 0.827$ (49)
$s_e = 31$

In these equations the independent variables were significant at the risk < 0.1 per cent, except for P_a in eq. (44) and (48), $C + I_s$ in eq. (49), which are significant at the risk < 1 per cent, and I_s in eq. (48) (risk < 5 per cent). The equation (45) is presented as a nomograph in Fig. 12.

The instantaneous summer maximum runoff with return period of 20 years ($Hq_{s\,inst}$ 1/20) was best explained by drainage area ($A^{-1/3}$, r = 0.84), drainage density (D_d, r = 0.77) and the percentages of fine soils (G_f^2, r = 0.78; G_c^2, r = 0.70). The dependent variable could be explained with high degree of determination, but a great number of the best combinations had to be rejected due to unacceptable distribution of the residuals. In eqs. (50) — (55) some acceptable combinations for $Hq_{s\,inst}$ 1/20 are presented.

$\overline{Hq_{s\,inst}\ 1/20} = 235\ l\ s^{-1}\ km^{-2}$, $s_y = 261\ l\ s^{-1}\ km^{-2}$

$Hq_{s\,inst}\ 1/20 = 457\ A^{-1/3} - 43$
$R = 0.836$ (50)
$s_e = 145$

$$Hq_{s\ inst}\ 1/20 = 389\ A^{-1/3} - 346\ F_s^{1/9} + 517$$
$R = 0.899$ (51)
$s_e = 118$

$$Hq_{s\ inst}\ 1/20 = 302\ A^{-1/3} + 0.106\ (I_s + G_f)^2 - 12$$
$R = 0.917$ (52)
$s_e = 107$

$$Hq_{s\ inst}\ 1/20 = 357\ A^{-1/3} + 0.064\ (C + I_s)^2 - 1.30\ (C + I_s) - 14$$
$R = 0.901$ (53)
$s_e = 118$

$$Hq_{s\ inst}\ 1/20 = 394\ A^{-1/3} + 0.052\ C^2 + 21\ b_i - 83$$
$R = 0.907$ (54)
$s_e = 115$

$$Hq_{s\ inst}\ 1/20 = 322\ A^{-1/3} + 0.12\ (G_f + I_s)^2 + 26\ b_i - 74$$
$R = 0.934$ (55)
$s_e = 97$

In these equations the independent variables are significant at the risk < 0.1 per cent, except for b_i in eqs. (54) and (55), and $C + I_s$ in eq. (53), which are significant at the risk < 5 per cent. The equation (55) is presented as a nomograph in Fig. 13.

5. RUNOFF RATIOS

5.1 Spring

The instantaneous spring maximum runoff ($MHq_{w\ inst}$) was on average 1.31 times the daily spring maximum (MHq_w) and a standard deviation of 0.23. In the following some combinations for the relationship of $MHq_{w\ inst}/MHq_w$ are presented, eqs. (56) — (59).

$$MHq_{w\ inst}/MHq_w = 0.35\ A^{-1/3} + 1.09$$
$R = 0.732$ (56)
$s_e = 0.16$

$$MHq_{w\ inst}/MHq_w = 0.28\ A^{-1/3} + 0.0044\ (C + I_s) + 1.05$$
$R = 0.837$ (57)
$s_e = 0.13$

$$MHq_{w\ inst}/MHq_w = 0.29\ A^{-1/3} + 0.0044\ C + 1.05$$
$R = 0.835$ (58)
$s_e = 0.13$

$$MHq_{w\ inst}/MHq_w = 0.21\ A^{-1/3} + 0.0047\ C - 0.067\ t_w + 1.17$$
$R = 0.865$ (59)
$s_e = 0.12$

All the independet variables were significant at the risk < 0.1 per cent, except for t_w in eq. (59), which

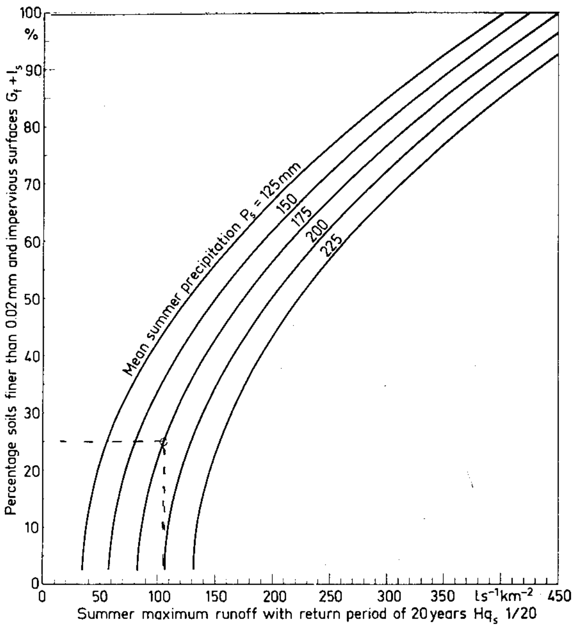

Fig. 12. A nomograph for the summer maximum runoff with return period of 20 years $Hq_s 1/20 = 0.037\ (G_f + I_s)^2 + 0.97\ P_s - 88$.

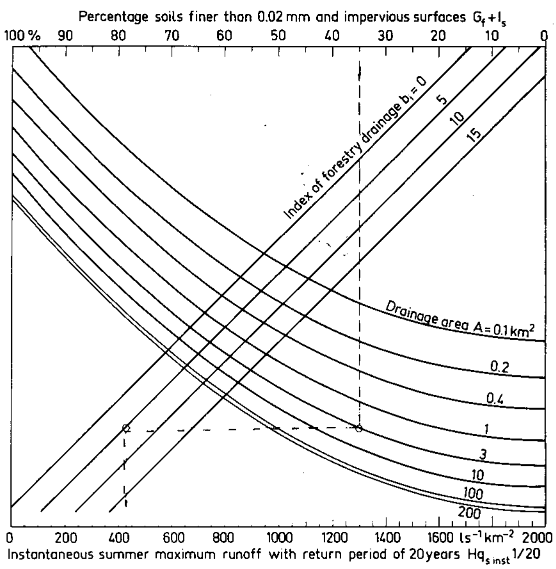

Fig. 13. A nomograph for the instantaneous summer maximum runoff with return period of 20 years $Hq_{s\ inst}\ 1/20 = 322\ A^{-1/3} + 0.12\ (G_f + I_s)^2 + 26\ b_i - 74$

3 128300922D—12

was significant at the risk < 5 per cent.

According to the equation (57) the relationship $MHq_{w\ inst}/MHq_w$ for a basin consisting 100 per cent cultivated land and impervious surfaces is 34 per cent greater than for a forested basin.

The spring maximum runoff with return period of 20 years (Hq_w 1/20) was on average 1.91 times the mean spring maximum (MHq_w) and a standard deviation 0.26. In the following some combinations to explain the relationship $Hq_w\ 1/20/MHq_w$ are presented.

$$Hq_w\ 1/20/MHq_w = -0.0040\ W_p + 2.40$$
$$R = 0.577 \quad (60)$$
$$s_e = 0.22$$

$$Hq_w\ 1/20/MHq_w = -0.0031\ W_p - 0.0041\ G_r + 2.53$$
$$R = 0.636 \quad (61)$$
$$s_e = 0.21$$

In these equations the variable G_r in eq. (61) was significant at the risk < 5 per cent, the others were significant at the risk about 0.1 per cent. The ratio between spring maximum with return period of 20 years and the average spring maximum could not be explained at a satisfactory level.

The instantaneous spring maximum runoff with return period of 20 years ($Hq_{w\ inst}$ 1/20) was on average 1.92 times the instantaneous mean maximum ($MHq_{w\ inst}$), and a standard deviation of 0.27. In the following some combinations for the relationship $Hq_{w\ inst} 1/20/MHq_{w\ inst}$ are presented, eqs. (62) — (64).

$$Hq_{w\ inst}\ 1/20/MHq_{w\ inst} = -0.0044\ W_p + 2.47$$
$$R = 0.611 \quad (62)$$
$$s_e = 0.22$$

$$Hq_{w\ inst}\ 1/20/MHq_{w\ inst} = -0.0058\ W_m - 0.0048\ G_r + 2.84$$
$$R = 0.681 \quad (63)$$
$$s_e = 0.21$$

$$Hq_{w\ inst}\ 1/20/MHq_{w\ inst} = -0.0059\ W_m + 0.011\ G_f - 0.011\ C - 0.0066\ F + 3.00$$
$$R = 0.719 \quad (64)$$
$$s_e = 0.20$$

The independent variables were significant at the risk < 0.1 per cent, except for G_f in eq. (64) (risk < 1 per cent) and G_r in eq. (63), C and F in eq. (64) (risk < 5 per cent). The ratio $Hq_{w\ inst}$ 1/20 /$MHq_{w\ inst}$ could not be explained at a satisfactory level with the variables available.

The instantaneous spring maximum runoff with return period of 20 years ($Hq_{w\ inst}$ 1/20) was on average 2.50 times the daily mean maximum (MHq_w), and a standard deviation of 0.59. In the following some combinations for the relationship $Hq_{w\ inst}\ 1/20/MHq_w$ are presented, eqs. (65) — (71).

$$Hq_{w\ inst}\ 1/20/MHq_w = 0.025\ G_f + 2.15$$
$$R = 0.787 \quad (65)$$
$$s_e = 0.37$$

$$Hq_{w\ inst}\ 1/20/MHq_w = 0.83\ A^{-1/3} - 0.015\ F + 2.89$$
$$R = 0.854 \quad (66)$$
$$s_e = 0.31$$

$$Hq_{w\ inst}\ 1/20/MHq_w = 0.60\ A^{-1/3} + 0.014\ C + 1.88$$
$$R = 0.833 \quad (67)$$
$$s_e = 0.33$$

$$Hq_{w\ inst}\ 1/20/MHq_w = 0.60\ A^{-1/3} - 0.010\ F + 0.011\ G_f + 2.59$$
$$R = 0.882 \quad (68)$$
$$s_e = 0.29$$

$$Hq_{w\ inst}\ 1/20/MHq_w = 0.80\ A^{-1/3} - 0.011\ F_s + 0.20\ T_a + 2.01$$
$$R = 0.866 \quad (69)$$
$$s_e = 0.31$$

$$Hq_{w\ inst}\ 1/20/MHq_w = 0.40\ A^{-1/3} + 0.023\ G_f + 0.019\ B_o + 1.80$$
$$R = 0.876 \quad (70)$$
$$s_e = 0.29$$

$$Hq_{w\ inst}\ 1/20/MHq_w = 0.43\ A^{-1/3} + 0.020\ G_f + 0.020\ B_o - 0.0012\ E_p + 2.01$$
$$R = 0.893 \quad (71)$$
$$s_e = 0.28$$

In these equations the independent variables were significant at the risk < 0.1 per cent, except for F in eq. (68). A and B_o in eq. (70) (risk < 1 per cent) and G_f in eq. (68) and E_p in eq. (71) (risk < 5 per cent). The ratio $Hq_{w\ inst}\ 1/20/MHq_w$ was increased especially by an increase in fine soils (G_f), field percentage (C), annual temperature (T_a) and swamp percentage (B). Respectively it was decreased by a growth of drainage area (A), altitude (E_p), forest percentage (F) and tree stand (F_s).

5.2 Summer

The instantaneous summer maximum runoff ($MHq_{s\ inst}$)was on average 1.53 times the daily summer maximum (MHq_s) and a standard deviation of 0.67. The ratio could be explained with rather high degree of determination, eqs. (72) — (73).

$$MHq_{s\ inst}/MHq_s = 1.30\ A^{-1/3} + 0.74$$
$$R = 0.927 \qquad (72)$$
$$s_e = 0.26$$

$$MHq_{s\ inst}/MHq_s = 1.15\ A^{-1/3} + 0.10\ I_s + 0.70$$
$$R = 0.951 \qquad (73)$$
$$s_e = 0.21$$

The independent variables in these equations were significant at the risk < 0.1 per cent.

The summer maximum runoff with return period of 20 years (Hq_s 1/20) was on average 2.73 times the mean summer maximum (MHq_s) and a standard deviation of 0.61. In the following some equations for the ratio $Hq_s\ 1/20/MHq_s$ are presented, eqs. (74) — (76).

$$Hq_s\ 1/20/MHq_s = 0.28\ T_a + 1.94$$
$$R = 0.671 \qquad (74)$$
$$s_e = 0.46$$

$$Hq_s\ 1/20/MHq_s = 0.61\ A^{-1/3} - 0.0076\ W_e + 3.24$$
$$R = 0.768 \qquad (75)$$
$$s_e = 0.40$$

$$Hq_s\ 1/20/MHq_s = 0.19\ T_a + 0.00013\ C^2 + 0.096\ S_w + 2.00$$
$$R = 0.811 \qquad (76)$$
$$s_e = 0.37$$

In these equations the independent variables are significant at the risk < 0.1 per cent, except for S_w in eq. (76), which is significant at the risk < 1 per cent.

The instantaneous summer maximum runoff with return period of 20 years ($Hq_{s\ inst}$ 1/20) was on average 3.05 times the average instantaneous summer maximum ($MHq_{s\ inst}$) and a standard deviation of 0.99. The ratio $Hq_{s\ inst}\ 1/20/MHq_{s\ inst}$ could not be explained satisfactorily with the variables used, as shown in the equations (77) — (79).

$$Hq_{s\ inst}\ 1/20/MHq_{s\ inst} = 0.63\ D_d + 2.09$$
$$R = 0.598 \qquad (77)$$
$$s_e = 0.81$$

$$Hq_{s\ inst}\ 1/20/MHq_{s\ inst} = 0.45\ D_d + 0.24\ T_a + 1.69$$
$$R = 0.673 \qquad (78)$$
$$s_e = 0.75$$

$$Hq_{s\ inst}\ 1/20/MHq_{s\ inst} = 0.42\ T_a + 0.00068\ (C + I_s)^2 - 0.052\ C + 2.20$$
$$R = 0.732 \qquad (79)$$
$$s_e = 0.71$$

In these equations the independent variables are significant at the risk < 0.1 per cent, except for D_d in eq. (78) and C in eq. (79) (risk < 1 per cent) and T_a in eq. (78) (risk < 5 per cent).

The instantaneous summer maximum runoff with return period of 20 years ($Hq_{s\ inst}$ 1/20) was on average 4.97 times the daily average of summer maximum (MHq_s). The standard deviation of the ratio was 3.70. The ratio $Hq_{s\ inst}\ 1/20/MHq_s$ could be explained well, eqs. (80) — (84).

$$Hq_{s\ inst}\ 1/20/MHq_s = 7.3\ A^{-1/3} + 0.533$$
$$R = 0.941 \qquad (80)$$
$$s_e = 1.27$$

$$Hq_{s\ inst}\ 1/20/MHq_s = 6.8\ A^{-1/3} + 0.39\ T_a - 0.28$$
$$R = 0.952 \qquad (81)$$
$$s_e = 1.17$$

$$Hq_{s\ inst}\ 1/20/MHq_s = 6.6\ A^{-1/3} + 0.035\ G_f + 0.48$$
$$R = 0.952 \qquad (82)$$
$$s_e = 1.16$$

$$Hq_{s\ inst}\ 1/20/MHq_s = 6.7\ A^{-1/3} + 0.048\ G_f + 0.32\ b_i - 0.36$$
$$R = 0.964 \qquad (83)$$
$$s_e = 1.03$$

$$Hq_{s\ inst}\ 1/20/MHq_s = 7.3\ A^{-1/3} + 0.025\ C + 0.27\ b_i - 0.39$$
$$R = 0.956 \qquad (84)$$
$$s_e = 1.13$$

The variables in these equations are significant at the risk < 0.1 per cent, except for G_f in eq. (82), b_i in eq. (83) and C in eq. (84) (risk < 1 per cent) , and T_a in eq. (81) and b_i in eq. (84) (risk < 5 per cent).

6. INFLUENCE OF INDEPENDENT VARIABLES

From the regression equations and correlation coefficients some conclusions can be drawn as far as the significance of the independent variables is in concern.

The **drainage area** (A) did not markedly affect the daily mean maxima, but was a strong independent variable for the instantaneous and unusual maxima of the smallest basins. This was supported by the fact that area did not appear in the models developed without the three smallest basins (basins 11—13). These results can be considered logical, if the fact is taken into account that, in the case of basins of this size, all water from snowmelt and rainfall comes to the measuring point during one day (Mustonen 1965 c). For summer maxima the areal conciseness, on the other hand, may produce large daily maxima in the smallest areas due to the dependence of rainfall intensity on area. The best transformation of area was generally $A^{-1/3}$, which emphasizes the exceptionality of the smallest basins ($A < 1$ km^2). Almost as good was $A^{-1/2}$, which had, however, a skewer distribution than $A^{-1/3}$ or $A^{1/3}$.

For $Hq_{s\ inst}$ 1/20 the use of $A^{-1/3}$, $A^{-1/2}$, ln A and their inverse values tended to result in an unsatisfactory distribution of the residuals. For this reason the linear term of A was added, but it resulted in an illogical combination and could not be accepted.

Drainage area was the most effective independent variable in explaining the ratios of the exceptional to average and of the instantaneous to daily maximum runoff, i.e. the extremity and the peaked tendency of the basin and flood. The transformation $A^{-1/3}$ alone explained more than 85 per cent of the variances of the ratios $MHq_{s\ inst}/MHq_s$ and $Hq_{s\ inst}1/20/MHq_s$.

The **percentage of cultivated land** (C) increased in higher percentages especially instantaneous maxima both for spring and summer. The quadratic transformation appeared better than the mere linear one as shown earlier by Kaitera (1939) and Mustonen (1965 c) for the spring maximum. A general relative form for C was $-C + 0.017\ C^2$ for the daily spring maximum, which is somewhat less steep than those presented earlier. The minimum is reached at 29 per cent of C, when the relative decrease of spring maximum runoff is 13 per cent of the mean. The maximum relative increase was 59 per cent for 100 per cent cultivated land. The minimum presented by Kaitera occurred at about 15 per cent and that by Mustonen at 24 per cent.

The distribution of C and especially that of C^2 was rather skew and this may influence the results. However, the regression coefficients of C and C^2 were notably stable in different combinations and for different dependent variables. When the regression equations $Hq = f(C, C^2)$ were computed, the relative coefficients of the quadratic term were, with a value of C equal to -1, for MHq_w, $MHq_{w\ inst}$, Hq_w 1/20 and $Hq_{w\ inst}$ 1/20: 0.013, 0.018, 0.015, 0.020, respectively and for MHq_s to $Hq_{s\ inst}$ 1/20: 0.017, 0.029, 0.031 and 0.026, respectively. Hence the relative influence of the field percentage for the summer maximum runoff was greater than for the spring maximum, although C appeared in the spring models, but was substituted by fine soils in the summer models.

As could be expected, the field percentage increased the extremity and the peaked tendency of the basin. This was shown clearly in the ratios of the instantaneous to daily and of the exceptional to average, which were the greater, the more cultivated land there was in the basin. The increase of about three per cent in field percentage caused the increase of one percent in the ratio of $MHq_{w\ inst}/MHq_w$.

The **percentage of sub-drained field** (C_s) had no clear effect on maximum runoff, and it did not appear in the models, either. Results of an experimental study support this finding (Seuna and Kauppi 1982). The plot of C_s versus maximum runoffs showed a relationship resembling that of C, but weaker. It is to be noted, however, that the small variation of C_s restricts the explaining ability of this variable.

The **percentage of forest** (F) especially decreased spring maximum runoff but also the summer maximum. The primary reasons for the reduction are evidently the delay in the snowmelt conditions caused by forest and the permeable soils associated with forest ($r_{F,G_r} = 0.79$). However, forest percentage did not generally appear in the models due to a better independent variable, F_s.

Forest also decreased the extremity and the peaked tendency of maximum runoff, especially for the ratios of spring maximum runoff $MHq_{w\ inst}/MHq_w$, $Hq_{w\ inst}1/20/MHq_{w\ inst}$ and $Hq_{w\ inst}1/20/MHq_w$.

The **percentage of swampland** (B) had a decreasing effect on summer maximum runoff. It also appeared in some summer models. For spring maximum runoff there was no significant correlation; B did not come to these models, either.

Swamplands decreased the extremity of the maximum runoffs. Especially the runoff ratios of the summer maxima were decreased with the increase in the percentage of swamplands.

The **percentage of open bog** (B_o) increased spring maximum runoff, but decreased summer maximum. It also appeared in some spring models. In an open bog, snow is accumulated in an abundance (Mustonen 1965 a), and the conditions of snowmelt resemble those for cultivated land. It has been also presented (Kaitera 1939) that snowmelt waters are stored behind the snow banks of the bog and then abruptly discharged in high peaks. The decreasing effect on summer maxima could be caused by the storage capacity of such bog, which might cut the peaks to some extent. This conclusion is substituted by the runoff ratios of summer maximum runoffs, which are decreased by the increase of open bog. On the other hand, no influence caused by open bog on the extremity of spring runoffs could be observed.

The **percentage of forest-drained area** (B_d) did not show strong correlation with maximum runoff. It came to some summer models of Hq_s 1/20 with an increasing effect of about 1.5 l s^{-1} km^{-2} for one per cent's drained area. It seems evident that the decreasing effect of swampland (B_o and B) on summer maxima was removed by draining. On spring maximum runoff no influence of forestry drainage was observed.

The percentage of forestry drainage was in negative correlation with runoff ratios; however, to a smaller degree than the percentage of peatlands (B). This could be interpreted as a small growth in the extremity of runoff maxima.

The influence of **the index of forestry drainage** (b_i) did not differ from that of the mere drainage percentage, although the time factor was included in the index. However, b_i improved the residual distribution of the $Hq_{s\ inst}$ 1/20 equations in such a way that it was included in some final models.

The **percentage of impervious surfaces** including open bedrocks (I_s) explained the summer maximum runoff well. Because of the narrow variation range of I_s, the quadratic transformation, which would have been much better, was avoided in the final equations. Generally I_s was added to the field percentage (C) or to the percentage of fine soils (G_f and G_c). The combination 1.2 $(I_s)^2$ — 6.0 I_s, in equations of MHq_s would result in 11 400 l s^{-1} km^{-2} of runoff, if the drainage basin were completely impermeable. This is not probable, although the maximum 20 minutes rainfall with return period of 20 years amounts to 16 700 l s^{-1} km^{-2} in Finland (Kuusisto 1980). In an urban area, 67 per cent paved, the maximum peak of 5400 l s^{-1} km^{-2} has been measured (Melanen and Laukkanen 1981).

The increase of impervious surfaces also increased the extremity of maximum runoffs.

The **drainage density of main ditches** (D_d) showed a strong increasing effect on maximum runoff, especially those of summer. However, in the models it was mostly substituted by the drainage area (A) and field percentage (C). The regression coefficients of D_d for Hq_s 1/20 and $Hq_{s\ inst}$ 1/20 were approximately 36, while the mean density of main channels of the basins was 1.5 km^{-1}.

Drainage density also strongly increased the extremity of the basins, both for summer and spring maximum runoffs. For example, if the drainage density increased from one to two km^{-1}, the ratio of $MHq_{w\ inst}/MHq_w$ increased by 15 per cent.

The **volume of growing stock** (F_s) decreased spring maximum runoff and was one of the best independent variables for it. The increase of 1 m^3 ha^{-1} in tree stand caused a decrease of 0.7 l s^{-1} km^{-2} in the daily mean maxima, but a somewhat greater decrease in the instantaneous or exceptional maximum runoff. The plot of F_s vs. Hq showed a slight curvature. Of the several transformations tested, the third to twelfth roots of F_s showed the highest correlations with Hq (Table 7). The smaller roots better represented daily spring maxima; the highest ones fitted best to the instantaneous summer maxima. The root transformations improved a few models consisting of only one or two independent variables, but not the models containing more variables. As stated before, tree stand causes delay in snowmelt and also positively correlates with coarse soils, which both tend to decrease runoff peaks.

The **coverage of tree stand** (F_c) had much of a similar effect on the spring maximum runoff as the volume of growing stock. Usually information on the coverage of tree stand is not as easily available as that of F_s. For this reason it was omitted from the models, although it would have been even better for $MHq_{w\ inst}$ and $Hq_{w\ inst}$ 1/20.

The **percentage of coarse soils** (G_r) decreased both spring and summer maximum runoffs. It was a slightly weaker independent variable than the indices of fine soils (G_f and G_c) and did not enter the best models.

The coarse soils also reduced the extremity of maximum runoff. The index of coarse soils was also formed without fine sand moraine, but it proved to be a weaker independent variable than G_r. On the other hand, coarse soils better refer to low flows, on physical basis.

The **percentage of fine soils** (G_f) and the **percentage of clay soils** (G_c) correlated well with the summer maximum and the instantaneous spring maximum runoff. The increasing effect was

Table 7. Correlation coefficients between maximum runoffs and tree stand transformations.

	MHq_w	MHq_s	$MHq_{w\ inst}$	$MHq_{s\ inst}$	$Hq_w 1/20$	$Hq_s 1/20$	$Hq_{w\ inst} 1/20$	$Hq_{s\ inst} 1/20$
F	−0.24	−0.08	−0.40	−0.18	−0.43	−0.31	−0.53	−0.26
F_c	−0.52	−0.19	−0.54	−0.09	−0.53	−0.24	−0.55	−0.13
F_s	−0.63	−0.28	−0.53	−0.02	−0.60	−0.16	−0.51	0.01
$F_s^{1/2}$	−0.68	−0.38	−0.68	−0.21	−0.67	−0.34	−0.69	−0.23
$F_s^{1/3}$	−0.68	−0.42	−0.74	−0.33	−0.68	−0.45	−0.77	−0.37
$F_s^{1/4}$	−0.66	−0.45	−0.76	−0.40	−0.67	−0.51	−0.81	−0.46
$F_s^{1/6}$	−0.62	−0.46	−0.78	−0.47	−0.64	−0.57	−0.84	−0.55
$F_s^{1/8}$	−0.59	−0.47	−0.77	−0.51	−0.61	−0.59	−0.84	−0.59
$F_s^{1/10}$	−0.56	−0.47	−0.76	−0.53	−0.59	−0.61	−0.84	−0.62
$F_s^{1/12}$	−0.55	−0.46	−0.76	−0.54	−0.58	−0.61	−0.84	−0.63

best indicated in the quadratic transformation, such as e.g. $0.05\ G_f^2 - 1.1\ G_f$ for Hq_s 1/20. The quadratic transformation of G_c was avoided in the final equations because of the skewness of G_c^2 -distribution. Furthermore, G_f generally explained the variance better than G_c did. The influence of fine soils to a high degree equalled with that of the field percentage (C), which is natural considering the close correlation between them ($r = 0.86$). However, fine soils tended to especially explain summer maxima, while the field percentage explained those of spring. In the final models combinations of $G_f + I_s$ and $G_c + I_s$ were also used in order to obtain a better normality of the distribution of the independent variable. The distributions of the residuals were satisfactory for the mere G_f- and G_c -models as well.

Fine soils clearly increased the extremity of maximum runoff; more clearly than coarse soils reduced it.

The **percentage of gravel and gravel moraine** (G_g) did not show any notable effect on maximum runoff. For the most part this can be counted on the small variation of G_g.

The **length of the basin** (L_b) had a decreasing effect on the instantaneous summer maximum runoff. It evidently means a long travelling time for runoff and had, in fact, a closer correlation with maximum runoff than the drainage area (A) in linear form did. In the models L_b stayed away, when the transformations of drainage area were included.

The length reduced the extremity and the peaked tendency of maximum runoff, but did not generally enter the best models of runoff ratios, either.

The **elongation ratio of the basin** (k_e) affected the instantaneous summer maximum runoff in such a way that the bigger k_e, i.e. the less elongated, the greater and more peaky the maximum runoff. It was included in some summer models.

For the extremity the effect was parallel; the rounder the basin, the more extreme the maximum runoff.

The **circularity of the basin** (k_c) had a similar relationship with the maximum runoff as the elongation ratio did, which was expectable. It did not enter the best models. The circularity also increased the extremity and the peaked tendency of maximum runoff.

The **length of the main channel** (L_c) correlated very strongly with the length of the basin ($r = 0.97$). Of course the influence on runoff was almost identical with that of L_b and the opposite to k_e and k_c. The same holds true for the runoff ratios.

The **mean slope of the main channel** (S_c) increased the instantaneous summer maximum. Because of the skewness of its distribution it was generally rejected from the final models.

The slope increased the extremity and the peaked tendency of summer maxima remarkably.

The increase in **the distance from the centre of gravity to the outlet** (L_w) decreased the summer maximum runoff, but had not any notable effect on the spring maxima. It also reduced the extremity and the peaked tendency of maximum runoff, especially those for summer. The influence, naturally, is parallel to that of the drainage area.

The **slope from the centre of gravity to the outlet** (S_w) increased the instantaneous summer maximum runoff. Due to the skewness of the distribution it was generally rejected from the final equations. The slope also increased the extremity and the peaked tendency of summer maximum runoff, especially.

The **altitude of the basin** (E_w, E_o and E_p) was one of the best independent variables explaining spring maximum runoff especially. The most easily available of them, the altitude of the outlet (E_o) was in most cases also the best one. An increase of 10 meters in the altitude (E_o) resulted in an increase of 4 $l\ s^{-1}\ km^{-2}$ in spring maximum runoffs. The absolute increase almost equalled for various quantities of spring maximum runoff. Hence the relative influence of the altitude was greatest for MHq_W, which can also be seen from the correlation coefficients.

The altitude reduced the extremity of maximum runoffs. Especially the extremity of summer maxima decreased with the rise of the altitude. For the extremity and for the peaked tendency the maximum altitude was more effective than the altitude of the outlet.

The altitude has much the nature of an overall index: high altitudes generally mean in Finland a lot of snow ($r = 0.82$), a low percentage of cultivated land ($r = -0.61$) and fine soils ($r = -0.55$), and low annual temperature ($r = -0.76$).

The **maximum variation in the altitude** (E_d) behaved in the same way as the altitude indices did. It explained, however, much less of the variances of the maximum runoffs than the altitudes and thus did not enter the best models. The increase in the altitude difference reduced the extremity and the peaked tendency similarly to the absolute altitude. It is explained mainly by the high correlation between the difference and the altitude ($r = 0.88$).

The **mean slope of the basin** (S_m) increased the summer maxima, but decreased the spring maxima, according to the correlation coefficients. The mean slope did not prove to be as good an independent variable, as could be expected and did not come to the final equations. It was not effective in explaining the runoff ratios, either, although it increased the peaked tendency of exceptional summer maxima.

The **slope index** (s_i) increased the instantaneous summer maximum runoff, but was insignificant for the other runoff quantities. As far as the extremity and the peaked tendency of runoff is in concern, the slope index had an effect similar to the mean slope, but with much closer correlation ($r = 0.75$ and 0.71 for $MHq_{s\ inst}$ and $Hq_{s\ inst}$ 1/20 vs. MHq_s, respectively). Especially was the peaked tendency of summer maximum runoff increased by the slope index.

The **time of flow from the centre of gravity** (t_w) appeared to be a significant variable for summer maxima, especially. It would have improved the degree of determination of those models, but it was not included due to its laborious calculation. The shortening in the time of flow increased the peaked tendency of the maximum runoffs, both for spring and summer.

The **mean annual air temperature** (T_a) decreased the daily spring maximum by about 3 $l\ s^{-1}\ km^{-2}$ for 1°C. It was not as good as the altitude or snow cover and did not enter the best models. On the other hand the mean annual temperature remarkably increased the extremity and the peaked tendency of the maximum runoffs.

The **mean annual precipitation** (P_a) entered some of the equations for summer maximum runoff. An increase of ten millimeters in P_a caused an increase of about 3 to 4 $l\ s^{-1}\ km^{-2}$ in the summer maximum with return period of 20 years. The mean precipitation had no significant effect on the extremity of maximum runoffs, while it was in low positive correlation with the peaked tendency of summer maxima. The rather low correlation between precipitation and maximum runoff could be explained in two ways. First, the variation of mean annual precipitation is quite small in Finland and no especially rainy districts exist. Secondly, the high annual precipitation in the Finnish conditions does not necessarily mean heavy rainstorms, which are the basis for summer maximum runoffs. This conclusion can be drawn from the precipitation maps of Finland (Helimäki 1967, Lemmelä and Solantie 1977, Uppala 1978).

The **water equivalent of snow** (W_m, W_h, W_e, W_p) explained spring maximum runoff well, but not better than the altitude did. The influence of the average snowpack clearly decreased when moving from the daily mean maximum to the instantaneous and exceptional maximum runoff. There was no difference, practically speaking, between the various snowpack indices; therefore the average water equivalent of snow in 15 March, taken from the map, was mostly used. The water equivalent of snow also correlated with the summer maximum runoff (MHq_s) being in a way a general index for a northern location, high altitudes, a low percentage of cultivated land, and a moderate or high percentage of coarse soils.

The water equivalent of snow decreased the ratio of exceptional and average spring maximum runoffs, being in good agreement with an earlier study (Seuna 1977), which stated that the statistical distribution of snow cover for different years is much more uneven in southern and western Finland than in eastern and northern parts of the country. On the contrary, snow cover did not affect the peaked tendency of runoff, which can also be concluded from an earlier study (Mustonen 1965 c).

The **average summer precipitation** (P_s)

influenced quite parallelly with the annual precipitation. However, it was in a higher positive correlation with the spring maximum runoff than the annual precipitation. This again stems from low altitudes, high percentage of cultivated land, and vicinity of the coast, all of which are associated with low summer precipitation. The summer precipitation did not markedly affect the extremity or the peaked tendency of maximum runoffs.

7. DISCUSSION

The statistical characteristics of both spring and summer maximum runoff could be explained at a rather satisfactory level using only physiographic characteristics of the basins and some climatological factors, which are readily available beforehand. From a practical point of view this is important considering the design of hydraulic engineering works for unobserved basins.

The regression coefficients were, although dependent on the other parameters in the equations, generally rather stable. They grew logically with the increase in the variances of various dependent variables.

To ensure the applicability of the equations obtained, the residuals of the models were analysed (Figs. 14 and 15). On this basis and because of the skewness of some transformations of the independent variables, a number of equations were rejected. A considerable number of them fitted to the data better than respective equations presented here. It is still to be noted, however, that the independent variables should not be used for practical planning much beyond the range of the data base.

The peaked tendency and the extremity of the maximum runoff, i.e. ratios of the instantaneous to daily and the ratio of the exceptional to mean maximum were affected by many of the same factors. Those characteristics were especially promoted by fine soils (G_f, G_c), cultivated land (C), impervious surfaces (I_s), drainage network (B_d, b_i, D_d), slope of the basin (S_c, S_w, S_m, s_i) and high annual mean temperature (T_a). On the other hand the extremity and the peaked tendency were decreased by the increases in drainage area (A, L_b, L_c, L_w), in coarse soils (G_r), in altitudes (E_o, E_w, E_p) and in abundance of snow (W_m, W_h, W_e, W_p).

The most effective factors influencing the exceptional spring maximum, compared with mean maximum, were the amounts of snow and coarse soils, both of which tended to decrease this variation. An abundance of fine soils, drainage density and a small drainage area, respectively, were the most important factors in sharpening the peak of spring flood.

For summer the exceptional maximum as compared with the mean was most affected by the annual temperature and drainage density. Respectively the drainage area alone explained more than 85 per cent of the variance of the peaked tendency for

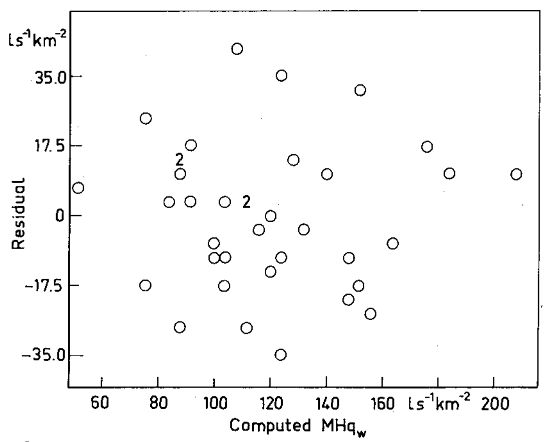

Fig. 14. An example of a satisfactory distribution of the residuals. The equation $MHq_w = 0.018\ (C + I_s)^2 - 1.2\ (C + I_s) - 0.50\ F_s + 0.29\ E_o + 126$, $R = 0.875$, has been used.

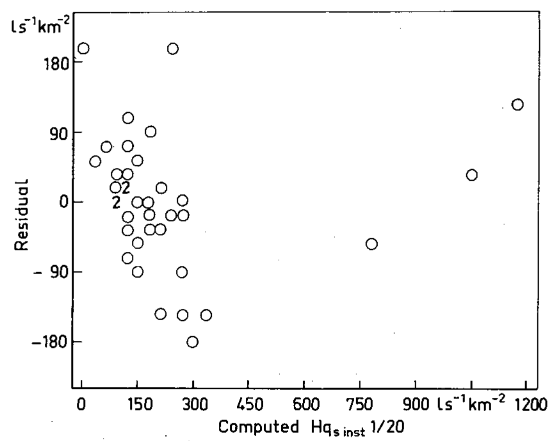

Fig. 15. An example of an unsatisfactory distribution of the residuals. The equation $Hq_{s\ inst}\ 1/20 = 477\ A^{-1/2} + 5.6\ I_s^2 - 109\ S_w + 57$, $R = 0.944$, has not been accepted.

the summer flood.

In general the peaked tendency of flood could be much better explained than the relationship between exceptional maximum and mean maximum. This was the case both for spring and for summer.

Some of the characteristics evidently have a nature of a multiple coefficient. Such is e.g. drainage area, as shown in literature (e.g. Kaitera 1939, Renqvist 1933). In this context multiple combinations were not used, however, because the significance of the individual independent variables was wanted to be compared. The polynomial models used in this study are not necessarily physically-based, but they can be considered acceptable for practical purposes and for giving good suggestions for further research. In later studies multiple combinations should be tested.

Restrictions of regression analysis have been widely discussed in literature (e.g. Mustonen 1965c, Yevjevich 1972, Daniel and Wood 1980). Especially have the difficulties risen by intercorrelations of the independent variables been pointed out. Strictly speaking regression analysis should not be employed in such a case at all, if mathematical orthodoxy is followed. In hydrological phenomena, however, the intercorrelations are inevitable, and no practical solution exists to produce useful combinations of parameters, i.e. design models, except for regression analysis. On the other hand, the main purpose, also in this study, is to obtain combinations of readily available variables to explain satisfactorily the variation of a certain runoff quantity, but not that much to investigate the physical relationships. For these reasons the use of regression analysis can be considered justified.

The use of regression analysis also presupposes other requirements, such as the normality of the distribution of the variables and the residuals. An independent variable should also have a range wide enough in order to be meaningful in the regression equations. Due to these requirements a number of transformations and equations had to be rejected. Totally some 1500 different combinations of variables were tested.

ACKNOWLEDGEMENTS

This study has been based on the data provided by the National Board of Agriculture and by the National Board of Waters in Finland. The local observers — about 200 in all — have been important in producing the data. The construction and the maintenance of the measuring weirs have been carried out mainly by the local Water Districts' Offices and their predecessors.

A number of persons have contributed to the study. Among them I especially wish to thank Mr. Teppo Järvi for carrying out the computational tasks, Mr. Timo Nieminen and Mr. Heikki Susimaa for assisting in the collection and the processing of data and Mr. Veikko Salmipuro and Mr. Tapio Saarenketo for a remarkable assistance in the maintenance of the network.

The manuscript was commented by Prof. Seppo E. Mustonen, for which I express my gratitude.

Finally I want to thank Ms. Eeva-Liisa Alanne for typing the manuscript, Ms. Terttu Halme for drawing the figures and Ms. Raili Malinen for making the layout.

Tuusula December 1982

Pertti Seuna

TIIVISTELMÄ

Tässä tutkimuksessa on kehitetty joukko regressiomalleja kevät- ja kesäylivalumalle käytännön suunnittelu- ja mitoitustarpeita varten. Perusaineistona on käytetty vesihallituksen hydrologian toimiston pienten valuma-alueiden havaintoja ja niiden perusteella laadittuja toistuvuusanalyyseja yli 10 vuoden havaintosarjoille 37 alueelta. Selitettävinä muuttujina ovat olleet keskimääräinen ja keskimäärin kerran 20 vuodessa sattuva ylivaluman vuorokausiarvo ja hetkellinen arvo sekä keväälle että kesälle. Lisäksi on laskettu hetkellisen ja vuorokautisen ylivaluman sekä kerran 20 vuodessa sattuvan ja keskimääräisen ylivaluman suhteille regressioyhtälöitä. Selittävinä muuttujina on käytetty kartoilta tai tilastoista etukäteen saatavia aluetekijöitä sekä ilmastotekijöistä pitkän jakson keskiarvoja.

Valitut ylivalumien tunnusluvut on ollut yleensä mahdollista selittää käytännön tarpeisiin riittävällä tarkkuudella käyttämällä 2—4 muuttujaa. Hetkellisten huippujen ja vuorokausiarvojen suhde on selittynyt selvästi paremmin kuin kerran 20 vuodessa sattuvien ylivalumien suhde keskimääräisiin.

Parhaita selittäjäryhmiä ovat olleet maaperätekijät, alueen sijainti ja korkeusasema sekä puusto. Hienot maalajit ovat selittäneet erityisesti kesäyli-

valumia kun taas avoimet alueet, lähinnä peltojen osuus, ovat selittäneet paremmin kevätylivalumia. Valuma-alueen korkeusasema, yleensä ilmaistuna alimman pisteen korkeutena, on osoittautunut erittäin hyväksi kevätylivaluman selittäjäksi, mutta se on selittänyt hyvin myös kesäylivalumia. Korkeusasemaa on pidettävä eräänlaisena yleisindeksinä; sen suuri arvo merkitsee samalla pohjoista sijaintia, runsasta lumen määrää ($r = 0.82$), vähäistä pellon ($r = -0.61$) ja hienojen maalajien osuutta ($r = -0.55$) sekä matalaa vuoden keskilämpötilaa ($r = -0.76$). Valuma-alueen ala on selittänyt voimakkaasti kesäylivalumia ja ylivalumien huipukkuutta, samoin on tehnyt uomatiheys, vaikka se on jäänytkin yleensä alan rinnalla pois malleista. Alueen topografialla ei ole ollut — eikä geometrisilla tekijöilläkään — merkittävää vaikutusta selitettäviin muuttujiin, joskin kaltevuuden lisääntyminen on lisännyt ylivaluman äärevyyttä, erityisesti kesähuippujen osalta. Ilmastotekijöistä pitkän jakson lämpötila, sadanta ja lumen vesiarvo ovat olleet tärkeitä ylivaluman selittäjiä.

Regressiomalleja kehitettäessä on kokeiltu likimain 1500 muuttujayhdistelmää, joista muutamat on kehitetty nomogrammeiksi (kuvat 3—13).

Regressioanalyysin käyttöön sisältyy joukko vakavia ongelmia, kuten selitettävien muuttujien väliset korrelaatiot, muuttujien ja selitysvirheiden jakaumien epänormaalisuus sekä muuttujien vaihteluvälin kapeus ja vinous (kuvat 14 ja 15). Puhtaasti matemaattisin perustein olisikin regressioanalyysin käyttö monissa luonnontieteellisissä yhteyksissä hylättävä. Käytännössä tarvittavien muuttujayhdistelmien tuottamiseen regressioanalyysia on kuitenkin pidettävä käyttökelpoisena menetelmänä, vaikka todellisia fysikaalisia vuorosuhteita ei välttämättä aina saadakaan esille. Silloin kun muuttujan regressiokerroin eri muuttujayhdistelmissä pysyy vakaana, voidaan vuorosuhteen katsoa kuitenkin antavan informaatiota kyseisen tekijän todellisestakin vaikutuksesta.

LIST OF SYMBOLS

MHq_w	= mean value of spring maximum runoff	$l\ s^{-1}\ km^{-2}$
MHq_s	= mean value of summer maximum runoff	$l\ s^{-1}\ km^{-2}$
$MHq_{w\ inst}$	= mean value of instantaneous spring maximum runoff	$l\ s^{-1}\ km^{-2}$
$MHq_{s\ inst}$	= mean value of instantaneous summer maximum runoff	$l\ s^{-1}\ km^{-2}$
$Hq_w\ 1/20$	= spring maximum runoff with return period of 20 years	$l\ s^{-1}\ km^{-2}$
$Hq_s 1/20$	= summer maximum runoff with return period of 20 years	$l\ s^{-1}\ km^{-2}$
$Hq_{w\ inst} 1/20$	= instantaneous spring maximum runoff with return period of 20 years	$l\ s^{-1}\ km^{-2}$
$Hq_{s\ inst} 1/20$	= instantaneous summer maximum runoff with return period of 20 years	$l\ s^{-1}\ km^{-2}$
A	= drainage area	km^2
C	= cultivated land	% of area
C_s	= sub-drained cultivated land	% of area
F	= forest	% of area
B	= swampland	% of area
B_o	= open bog	% of area
B_d	= forestry drainage	% of area
b_i	= index of forestry drainage $= \sum \frac{d_i}{t_i}$	
d_i	= percentages of different drainages	% of area
t_i	= time in years from each drainage	
I_s	= paved surfaces and open bedrock	% of area
D_d	= drainage density of main ditches	km^{-1}
F_s	= volume of growing stock in total drainage area	$m^3\ ha^{-1}$
F_c	= coverage of tree stand	% of area
G_r	= percentage coarse soils (gravel, coarse to fine sands, coarse silt and respective moraines)	% of area
G_f	= percentage fine soils (clay, fine and medium silts and respective moraines)	% of area
G_c	= percentage clay soils	% of area
G_g	= percentage gravel soils	% of area
L_b	= length of basin along main channel	km
k_e	= elongation ratio $= A / (L_b)^2$	

k_c	= circularity of basin = A / A_p	
A_p	= area of a circle with equal perimeter	km^2
L_c	= length of main channel	km
S_c	= mean slope of main channel	%
L_w	= distance from outlet to the centre of gravity	km
S_w	= slope from centre of gravity to outlet	%
E_w	= altitude of centre of gravity	m a.s.l.
E_o	= altitude of outlet	m a.s.l.
E_p	= maximum altitude of basin	m a.s.l.
E_d	= maximum difference in altitude	m
S_m	= mean slope of basin	%
s_i	= slope index = relief ratio = ratio between mean altitude of the water divide referred to outlet and divided by basin length	$m\ km^{-1}$
t_w	= time of flow from the centre of gravity to the outlet = $L_w(2n)^{3/4}Q^{-1/4} S_w^{-3/8}/3600$	h
T_a	= mean annual air temperature	°C
Q	= $MHQ_{s\ inst}$	$m^3\ s^{-1}$
n	= the Manning coefficient	
P_a	= mean annual precipitation (corrected)	mm
P_s	= average precipitation of June to August	mm
W_m	= water equivalent of snow on 15 March as long-term average	mm
W_h	= water equivalent of snow on average during study period on 15 March	mm
W_e	= water equivalent of snow on average during study period on 31 March	mm
W_p	= maximum water equivalent of snow on average during study period	mm
s_y	= standard deviation	
s_e	= standard error of estimate	

REFERENCES

Daniel, C. & Wood, F.S. 1980. Fitting equations to data. 458 p. J. Wiley & Sons. New York.

Helimäki, U.I. 1967. Tables and maps of precipitation in Finland, 1931—1960. Supplement to the meteorological yearbook of Finland 66:2. Helsinki.

Kaitera, P. 1939. Lumen kevätsulamisesta ja sen vaikutuksesta vesiväylien purkautumissuhteisiin Suomessa. (On the melting of snow in springtime and its influence on the discharge maximum of watercourses in Finland, in Finnish). 255 p. Helsinki. Maataloushallituksen kulttuuriteknillisiä tutkimuksia 2.

Kuusisto, E. 1980. On the intensity of rainfall in Finland. Aqua Fennica 10:3—11.

Lemmelä, R. & Solantie, R. 1977. Maps of Finland's water balance elements. Nordic Hydrology 8:281—288.

Melanen, M. & Laukkanen, R. 1981. Quantity of storm runoff water in urban areas. Helsinki. Publications of the Water Research Institute 42:3—39.

Mustonen, S. 1964. Ojituksen vaikutuksesta suon hydrologiaan. Summary: The influence of drainage on hydrology of peat land. Rakennustekniikka 3:204—209.

Mustonen, S. 1965a. Ilmasto- ja maastotekijöiden vaikutuksesta lumen vesiarvoon ja roudan syvyyteen. Summary: Effect of meteorologic and terrain factors on water equivalent of snow cover and on frost depth. 36 p. Helsinki. Acta Forestalia Fennica 79.

Mustonen, S. 1965b. Hydrologic investigations by the Board of Agriculture during the years 1957 to 1964. 144 p. Helsinki. Soil and hydrotechnical investigations 11.

Mustonen, S. 1965c. Meteorologisten ja aluetekijöiden vaikutuksesta valuntaan. Summary: Effects of meteorologic and basin characteristics on runoff. 109 p. Helsinki. Soil and hydrotechnical investigations 12.

Niinivaara, K. 1961. Ylivalumien todennäköisestä vaihtelusta Suomen päävesistöjen alueilla. (Statistical variation of maximum runoff in the main watercourses of Finland, in Finnish). Tekn. aikakauslehti 18.

Renqvist, H. 1933. Sadealueen suuruuden vaikutuksesta tulvamäärään. (Dependence of drainage area on flood, in Finnish). Tekn. Aikakauslehti 1, Helsinki.

Seuna, P. 1977. Lumen vesiarvon vaihtelusta Suomessa. Summary: On the variation of the water equivalent of snow in Finland. Vesitalous 2:5—7.

Seuna, P. 1982. Frequency analysis of runoff of small basins. 77 p. Helsinki. Publications of the Water Research Institute 48.

Seuna, P. & Kauppi, L. 1982. Influence of subdrainage on water quantity and quality in a cultivated area in Finland. Helsinki. Publications of the Water Research Institute 43:32—47.

Uppala, S. 1978. Extreme distributions for daily and monthly precipitation in Finland. Helsinki. Geophysica 15, 1:17—39.

Yevjevich, V. 1972. Probability and statistics in hydrology. 302 p. Water Resources Publications. Fort Collins.